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Coming in February

Look for: **Feature Reports** on Vapor Recovery Units; and Pipes, Joints and Fittings; A **Focus** on Particle Sizing Equipment; A **Facts at your Fingertips** on Plant Safety; a **Newsfront** on Process Analytical Technology; **New Products**; and much more

Cover design: Tara Bekman

Editor's Page

CPI outlook is adjusting and strong

Following the major disruptions in 2020 due to the pandemic, U.S. chemical production has grown in 2021 and is poised for further gains in 2022, according to the American Chemistry Council's *Year-End 2021 Chemical Industry Situation and Outlook*. U.S. chemistry is expected to grow by over 4% in 2022. Martha Moore, who is ACC's chief economist and author of the report, says that "While risks for the global economy remain, the U.S. chemical industry is in a strong position going into 2022 … American chemistry is poised to accelerate as strong consumer demand and restocking drive growth."

Strong demands tempered by supply and weather

After widespread lockdowns and hefty economic stimulus efforts during the pandemic, consumer demand for durable goods surged in 2021. Two large markets for chemical products, vehicles and housing, both saw expanding demand this past year.

And while demand was strong, vehicle production could not keep up because of supply constraints, specifically from semiconductor manufacture. In fact, supply-chain disruptions have affected just about every segment of production within the chemical process industries (CPI). In addition to supply-chain bottlenecks, significant weather events — in the U.S. most notably, the unusual freeze and a hurricane in the Gulf Coast — also contributed to lower inventories of basic chemicals. Production being held back by supply-chain disruptions, however, is expected to rebound as those issues are resolved and consumer demand remains high.

CPI trends

As the CPI continue to adjust to meet demands while weathering numerous disruptions, they are also keenly addressing longterm challenges and adjusting their focus accordingly. As mentioned in this column last month, ambitious climate-change targets are fueling work in areas such as carbon capture and storage, and "green" hydrogen production. Overall, sustainability and process efficiency goals are driving attention to recycling (particularly of plastics), bio-based chemistry and ways to increase efficiency, such as catalyst developments — see for example our Cover Story on the Kirkpatrick Chemical Engineering Achievement Award.

As mentioned, the automobile market is a major user of CPI products. Vehicle manufacturers' movement away from petroleum-derived fuels and toward electric cars or possibly hydrogen as a fuel source, affects the products to be provided to them by the CPI. Examples include developments in battery chemistry and polymer chemistry.*

And, corporations are preparing for changing needs via business ventures. Last month, BASF (www.basf.com) announced a new standalone business called BASF Automotive Catalysts and Recycling, which is being formed specifically to focus on the changes expected in the automobile market. And recently, TotalEnergies (totalenergies.com) partnered with Plastic Omnium (www.plasticomnium.com) to design and develop new plastic materials, made from recycled polypropylene, for the automobile industry.

We look forward to continuing to cover these trends and much more throughout the year, and we wish our readers all the best for this new year. ■

Dorothy Lozowski, Editorial Director

* see Electric Vehicles Drive Performance Polymers, *Chem. Eng.* August 2021, pp. 13–16

Edited by:
Gerald Ondrey

'Crystallized' hypochlorous acid brings enhanced antimicrobial performance

A new solid form of hypochlorous acid (HOCl) is showing promise as a highly effective antimicrobial agent. PCT Ltd. (Little River, S.C.; www.para-con.com) and Onza Corp. (Denver, Colo.; www.onzacorp.com) achieved what is said to be the industry's first-ever successful "crystallization" of HOCl and rehydration back into liquid HOCl, while maintaining all the chemical properties of the original HOCl. "We entrapped hypochlorous acid between the crystal boundaries and fluid inclusions in an erythritol-based matrix using Stevia in this first test," explains Paul Mendell, co-founder of Onza. Onza's proprietary gas-trapping technology enables much easier transport and application of chemical products, since they can be stored as a dry, stable solid rather than in their gaseous form, effectively extending products' useful life and application range. Onza is also working on gas-entrainment technologies for ozone, nitric oxide, chlorine dioxide and hydrogen sulfide. The crystals were manufactured at Noble Analytical Laboratory in Pampa, Texas by Victoria McDowell.

After about a week of exposure to air at room temperatures, the team tested the HOCl crystals against non-pathogenic *E. coli* on a stainless-steel surface at an independent laboratory, and the test revealed antimicrobial activity greater than the control


PCT

(using Stevia alone) — resulting in a 95% reduction in the *E. coli* colony.

"While this first test proved antimicrobial activity, we plan to improve efficacy. The goal will be to expand the application of hypochlorous acid (and other disinfectants), by offering new, alternative delivery forms and hopefully greater stabilization of otherwise sensitive or unstable compounds," adds Mendell. Future work will involve analyzing different crystal structures and compositions, and conducting efficacy studies with the U.S. Environmental Protection Agency (EPA).

Layered catalyst selectively generates two-carbon compounds from CO_2

Copper-catalyzed electrochemical reduction offers a path for making valuable chemicals, such as ethanol or ethylene, from CO_2. However, selectively generating sufficient yields of two-carbon products requires precise manipulation of the microenvironment near the surface to control reaction activity and product selectivity.

Recent research from the Lawrence Berkeley National Laboratory (LBL; Berkeley, Calif.; www.lbl.gov) has demonstrated progress toward a catalyst system capable of activity and selectivity for C2 products that vastly outstrips those of copper alone. The LBL approach relies on layering two ion-conducting polymers — one a perfluorosulfonic acid, cation-conducting ionomer (Nafion); the other a polystyrene-based, anion-conducting ionomer (Sustainion) — onto a copper surface to catalyze the electrochemical reduction.

"The Sustainion layer boosts the concentration of CO_2 relative to that of H_2O at the catalyst surface because the CO_2 affinity and hydrophobicity of this ionomer, make it more likely that carbon-carbon coupling will occur," explains Alexis Bell, senior scientist at LBL and professor of chemical engineering at the University of California at Berkeley (www.berkeley.edu). "Meanwhile, the Nafion raises pH near the copper surface by trapping hydroxyl ions, thereby suppressing the formation of H_2 and C1 products."

Further enhancement of the surface effects of the bilayer ionomer films is achieved by altering the cathode voltage by applying five-second pulses, generating Faraday efficiencies of over 90% for C2 products, and only 4% for hydrogen formation.

In the future, Bell and his team plan to investigate methods to coat copper nanoparticles with the bilayer ionomers. The concept of layering ionomers can also be applied to other catalyst systems.

CO_2 SEPARATION

Conventional DDR-type zeolite membranes are well suited for separating CO_2 from different-sized molecules, such as methane, which is present in associated gas or natural gas. However, such membranes are not very efficient for separating CO_2 from O_2 or N_2, which is common in many industrial exhaust-gas streams. Now, a new DDR-type zeolite membrane, developed by NGK Insulators, Ltd. (Tokyo, Japan; www.ngk-insulators.com) has been demonstrated to be five times more efficient than conventional DDR-type zeolite membranes for separating CO_2 from such exhaust gases.

Unlike conventional zeolite membranes that perform the separation on the difference in molecule's size, the new membrane makes use of the different adsorption characteristics (affinity) for molecules to separate CO_2 from N_2 and O_2. Taking advantage of the stable properties of ceramics under harsh conditions, the company is working to increase the separation factor even further for applications involving high-temperature industrial exhaust gases. Following more testing and development, the company is targeting a commercial launch in 2030.

GAS SWEETENING

TechnipFMC plc (Newcastle Upon Tyne, U.K.; www.technipfmc.com) and Petronas Technology Ventures Sdn Bhd (PTVSB), a subsidiary of Petronas (Kuala Lumpur, Malaysia; www.petronas.com), recently entered into an agreement to commercialize a unique natural-gas processing membrane that reduces

(Continues on p. 6)

greenhouse gas (GHG) emissions. Through the technology-commercialization agreement, TechnipFMC will utilize and integrate the membrane technology licensed from Petronas as part of its production portfolio in projects worldwide, outside China.

The technology, which removes CO_2 and H_2S by using "wetted membranes," is said to be 30% more efficient than existing gas-treatment processes and can reduce GHG emissions by significant amounts. The membrane has potential applications in both offshore and onshore hydrocarbon production environments.

NEW MEMBRANE MODULE

Toray Industries, Inc. (Tokyo, Japan; www.toray.com) has developed an exceptionally robust hollow-fiber ultrafiltration-membrane module that is suitable for purification and concentration processes in the food-and-beverage and biotechnology sectors. The module operates in steam (125°C) and hot water (90°C) environments, and can be steam sterilized.

Toray leveraged its high-strength polyvinylidene fluoride hollow-fiber membrane technology, which is already used in water-treatment applications, to develop a new module that employs an "outside-in" type crossflow-filtration design. Crossflow filtration is a common technique, whereby feed passes parallel to the membrane surface and prevents turbidity from accumulating. Pressure losses from this design are just one-third those of "inside-out" type that is normally used by food companies, says Toray. With the new design, it is possible to filter and concentrate highly turbid or viscous liquids, which is challenging with conventional membranes.

The new module has a large membrane area, which reduces the number of modules needed, reduces the space requirements by 50% and can potentially lower cleaning and equipment costs by more than 20%, Toray says.

SELF-HEALING CEMENT

Superior Energy Services (Houston; superiorenergy.com has launched RestoreCem , a self-healing cement system. RestoreCem's self-healing behavior enables it to regain its

(Continues on p. 7)

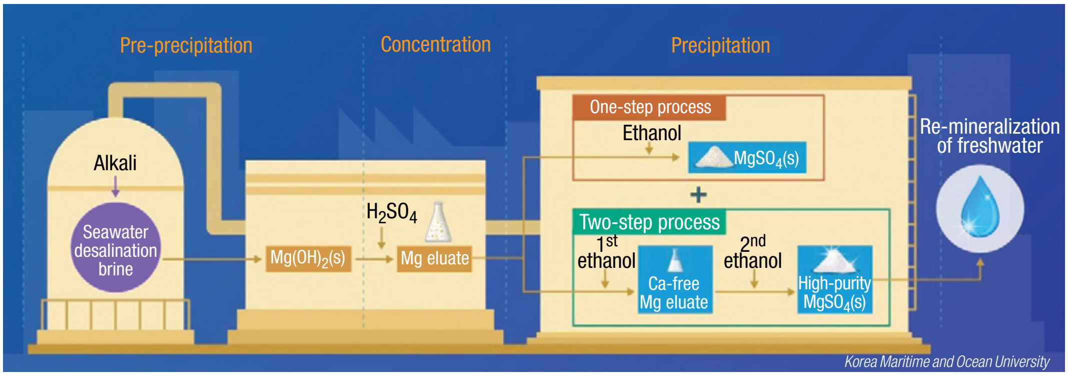
Extracting high-quality $MgSO_4$ from seawater desalination brine

A team of researchers, led by professor Myoung-Jin Kim, from Korea Maritime and Ocean University (Busan, South Korea; www.kmou.ac.kr), has developed a process that recovers calcium-free magnesium sulfate from seawater desalination brine (SDB). The process, described in a recent issue of *Desalination*, takes advantage of the difference in solubility of $MgSO_4$ and $CaSO_4$ in ethanol.

In the process (diagram), alkali is first added to SDB to precipitate $Mg(OH)_2$. The magnesium is concentrated by the addition of sulfuric acid. The eluate then undergoes a two-step addition of ethanol. First the ethanol dosage is adjusted so that only $CaSO_4$ is precipitated. After the Ca^{2+} has been removed, ethanol is further added to precipitate the high-purity $MgSO_4$. The magnesium recovery efficiency is 67%, producing 15.8 kg of $MgSO_4{\cdot}7H_2O$ from 1 ton of brine.

Because the purity of the recovered $MgSO_4$ was up to 99.8%, it could be used to re-mineralize fresh water after the seawater desalination process. According to a cost assessment of the process, high-purity $MgSO_4$ produced from seawater desalination brine is expected to be preferred over other $MgSO_4$ products that are used in the pharmaceutical and food markets, which require high-purity and economic feasibility.

"Since we have already developed a sophisticated seawater desalination process to address the world's water needs, why not couple it with the beneficial process of mineral extraction," says Kim.



Korea Maritime and Ocean University

Quantifying varnish removal in lubricated systems

In lubricated systems, varnish and deposits can form on metal surfaces as lubricant oils degrade, often leading to inefficient operations and equipment failure. There are many chemical cleaning products to break down varnish, but the effectiveness of these compounds in a particular system is difficult to quantify. To aid in selecting appropriate varnish-removing solutions for a particular application, Chevron Lubricants (San Ramon, Calif.; www.chevronlubricants.com) has partnered with the University of California at Merced (www.ucmerced.edu) to develop one of the industry's first testing system designed to study and compare the varnish removal efficiency of chemical cleaners.

The new test module includes an oil circulation unit, an imaging system and an image-analysis algorithm, which enables quantitative evaluation of varnish removal efficacy for chemical flushing fluids. An oil sample is heated and pumped through a specially designed test cell holding a metal plate containing a quantity of varnish film. The imaging system monitors varnish removal as the image-analysis algorithm generates corresponding data points, which are corroborated against weight measurements of the plate.

"We can study the varnish removal efficiency of chemical cleaners with different chemistries and treat rates at controlled operating conditions. Removal efficiency can be quantified as the total varnish removed over a given time or the rate of varnish removal. This approach also provides qualitative information about the varnish removal mechanisms for each cleaner using *in situ* videos of removal and post-test analysis of the varnish particles trapped on a downstream filter," says Zhen Zhou, senior formulator for Chevron.

Currently, the test system uses standard testing coupons, but the team is developing a module that is capable of measuring varnish removal on irregularly shaped metal parts in the field, such as valves and bearing pads, explains Zhou. The team believes that the testing unit could also be applied in other applications involving thin films and chemical circulation in the coatings and paint industry.

Predicting aluminum-alloy mechanical properties at high temperatures

Aluminum is used for a number of applications because it is lighter than iron and easy to machine. However, Al is usually alloyed with Cu, Mg or other elements for improved strength. Developing such alloys that maintain their strength at high temperatures (over 100°C) takes a lot of time, because it requires developers' knowledge-rich experience and performing many analysis and evaluations.

Aiming to solve these problems, Showa Denko K.K. (SDK; Tokyo, Japan; www.sdk.co.jp) has been participating in a project under Japan's Council for Science, Technology and Innovation (CSTI), Cross-ministerial Strategic Innovation Promotion Program. In this project, SDK, the National Institute for Material Science (NIMS; Tsukuba, Japan) and the University of Tokyo have collaboratively developed a computer system using neural networks — an artificial-intelligence algorithm — to accelerate the development of materials with optimal mechanical properties.

The researchers focused on 2000-series Al alloys (those that contain Cu and Mg), and utilized design data of 410 records of Al alloys listed in public databases, including the Japan Aluminum Assn., and developed neural network models (NNMs) that accurately predict the strength of Al alloys at various temperatures (from room temperature to over 200°C). In addition, the architecture and parameters of the neural network was optimized with Bayesian inference by applying the replica-exchange Monte Carlo method. This NNM can estimate — within 2 seconds — the alloy's strength under 10,000 different conditions.

An "inverse design tool" was also developed that suggests a set of Al-alloy design conditions that maximizes the probability of satisfying the desired strength at an arbitrary temperature. The models are said to shorten development time for Al alloys to about one-half to one-third of that required with conventional development methods.

Detail of the study were presented last month at a virtual session of the 2021 Materials Research Society's Fall meeting (December 6–8, 2021; www.mrs.org).

zonal isolation properties and restore the cement sheath against induced cracks, microfractures or micro annuli, minimizing the risk of cement sheath failures that can lead to hydrocarbon percolation within the set cement, or even blowouts. RestoreCem is said to have improved mechanical properties over conventional cement, providing set cement downhole with the resilience, endurance and elasticity to better withstand changes in stresses over the well production cycle. RestoreCem covers a wide range of downhole temperatures (80–300°F) and a wide range of slurry weights and densities.

SKIN TESTING

Evonik Industries AG (Essen, Germany; www.evonik.com) has invested

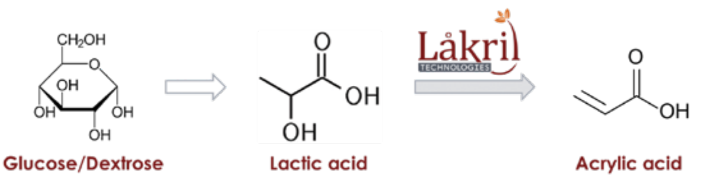
(Continues on p. 8)

in Revivo BioSystems Pte. Ltd. (Singapore; www.revivobio.com) — a spin-off of A*Star (Agency for Science, Technology and Research) — to support the development and commercialization of a technology that uses a realistic 4D model of human skin for the testing of chemical, cosmetic and pharmaceutical compounds. Revivo BioSystems' technology provides an alternative to animal testing that is also quicker, more reliable and cost efficient.

Revivo's organ-on-a-chip system simulates the interaction of human skin with the substance being tested. Skin tissues, which have been grown in a laboratory or a human skin sample, are placed on biochips that are supplied with nutrients and reagents. In this way, the technology creates a micro-environment for the tissue models, which reproduce the architecture and functions of skin. The system also automates testing and sampling procedures, enabling screenings that are required for regulatory approval of new substances. ❐

Bifunctional catalyst enables economically viable production of bio-based acrylates

Låkril Technologies



The prospects for a bio-based route to acrylates (diagram) received a significant boost recently, when startup company Låkril Technologies Corp. (Chicago, Ill.; www.lakril.com) licensed technology from the laboratory of Paul Dauenhauer at the University of Minnesota (Minneapolis, Minn.; twin-cities.umn.edu).

Dauenhauer has invented a catalyst said to be the first in the world capable of generating yields greater than 90% in the dehydration reaction of lactate to acrylate. Previous efforts to catalyze the reaction typically achieve yields of only 50–60% — too low to make the transformation an economically viable alternative to the petroleum-based route to acrylic acid (which is accomplished by the oxidation of propylene).

Låkril has obtained funding to scale up production of the catalyst and further develop the technology for commercial use. The company plans to start commercial production in late 2024.

The catalyst under development is an acidic solid zeolite (aluminosilicate) that has been functionalized with an engineered amine. The rationale for adding functionalization came out of previous mechanistic studies of the dehydration reaction. When lactate comes into contact with zeolite, dehydration or decarbonylation can occur, explains Chris Nicholas, co-founder and president of Låkril. The amine functionalization on the zeolite suppresses side reactions, including the primary one — decarbonylation, he says. The nature of the functionalized catalyst is proprietary, but is proposed to work wherein a base out-competes the weaker oxygenated functional groups on lactate, resulting in a higher coverage of base than lactate on Brønsted acid sites generated during reaction.

A technoeconomic analysis of the lactate dehydration process suggests that by suppressing side reactions and generating higher yields of acylate, the reaction moves into cost parity with the petroleum-based route, while reducing carbon intensity by at least 35%, Nicholas says.

Acrylates are industrially important for a range of products, including superabsorbent polymers in diapers, and as precursors for esters used in fibers, paints, adhesives and other products. With this new catalyst development, making more environmentally benign bio-based acrylates — by fermenting corn sugars into lactic acid, then dehydrating the lactic acid to acrylate — becomes economically attractive.

Bulk polymerization of elemental sulfur yields new flame-retardant plastics

A group of researchers from the University of Arizona (Tucson; www.arizona.edu), led by chemistry and biochemistry professor Jeff Pyun, are aiming to make use of sulfur waste streams from petroleum refineries. To meet environmental regulations, sulfur must be removed from crude oil during refining, but economic end-uses for high-volume sulfur streams are very limited.

"Typically, sulfur is very challenging to work with, as it is insoluble in most solvents and difficult to work with as a solid. Rather than trying to dissolve it, we developed a new process to melt elemental sulfur and use it as a monomer for polymerization," explains Pyun. The group developed a process called inverse vulcanization that uses sulfur as both the monomer and the salt for the polymerization reaction, resulting in a polymer with a sulfur-based backbone. Initially, the group looked at using the polymers in battery electrodes or optics materials, but they also wanted to investigate higher-volume end products, such as polyurethanes. To do so, Pyun's group split the polymerization process into steps, first starting with a prepolymer that is reacted with an olefin that carries an alcohol group, forming a high-sulfur-content precursor for segmented polyurethane products. "We're taking very inexpensive materials, such as sulfur and the alcohol 1-undecanol, and using them to make conventional plastics," adds Pyun.

These new sulfur-based polymers provided a valuable benefit over traditional polymers — flame retardancy. Typically, flame-retardant polymers involve either the addition of specialty monomers to conventional plastics, which drive up costs and inhibit large-scale production; or the addition of small-molecule flame-retardant agents, which are typically heavily halogenated, and introduce serious environmental concerns. The new sulfur-based polymers could unlock a pathway to cheaper, more sustainable flame retardants, says Pyun, noting that there are currently no similar products on the market. "I anticipate this chemistry should be scalable, as the materials and methods are inexpensive. The technology is also quite modular. We've chosen polyurethanes, but other polymers could certainly be made," adds Pyun.

Commercial production of glucaric acid from glucose

The synthetic biology company Kalion Inc. (Milton, Mass.; www.kalioninc.com) recently completed its first commercial-scale production run of high-purity (98–99%) glucaric acid via fermentation of glucose at a custom-manufacturing facility owned by Evonik Industries AG (Essen, Germany; www.evonik.com).

The high purities achieved by Kalion's advanced fermentation process far outstrip those achieved by existing bio-based glucaric acid processes at lower cost, widening the range of possible applications.

Combined with standard unit operations, the Kalion fermentation process uses proprietary synthetic biology techniques developed in the laboratory of Kristala Prather at Massachusetts Institute of Technology (MIT; Cambridge, Mass.; www.mit.edu) to engineer the metabolic pathways of *Escherichia coli* bacteria and induce efficient and low-cost production of glucaric acid.

The initial manufacturing produced material to meet existing customer commitments for high-purity glucaric acid. Among the customer applications is using glucaric acid as a corrosion inhibitor in cooling-water treatment. Glucaric acid obviates the need for phosphate-based inhibitors, which can have damaging effects when allowed to run off into coastal waters.

Darcy Prather, Kalion president and co-founder (along with his MIT-professor wife) points out that Kalion's glucaric acid would not be subject to the effluent restrictions now common to phosphate-based solutions, and production reduces greenhouse gas emissions by roughly 50% when compared with those alternatives.

"Use of high-purity glucaric acid expands the operating pH range in cooling water treatment," Prather says, and when used for corrosion inhibition in hard-water and high-temperature scenarios common at petroleum refineries, "glucaric acid does not cause the precipitate fouling with calcium that is observed with phosphate-based chemicals." The absence of precipitate preserves heat-transfer efficiency in heat exchangers and cooling systems.

While the water treatment market is Kalion's initial target, high-purity glucaric acid and related compounds can also enhance sustainability and improve performance as a polymer additive in textiles and coatings applications, as well as in detergents and pharmaceuticals. In textiles, for example, glucaric acid has been shown to increase modulus and tensile strength — by 50% to nearly an order of magnitude — for fibers such as polyvinyl alcohol, polyacrylic nitrile, recycled cotton and viscose (rayon) fibers, Prather says. Kalion is further developing these advantages in collaborations with fiber producers. ■

Business News

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Plant Watch

Air Liquide enters a longterm partnership for production of rare helium isotope

December 8, 2021 — Air Liquide S.A. (Paris; www.airliquide.com) entered into a longterm agreement with Laurentis Energy Partners to produce and distribute helium-3 (^{3}He), a rare isotope of helium used in quantum computing, astrophysics, neutron detection, medical imaging and more. Laurentis Energy Partners will extract helium-3 as a byproduct of the energy produced by the Darlington power-generating station in Canada. Air Liquide will use advanced cryogenics technology to purify the isotope, then package and distribute it.

Sabic and OQ studying joint petrochemicals complex in Oman

Sabic (Jubail, Saudi Arabia; www.sabic.com) signed a memorandum of understanding with OQ Chemicals GmbH (Monheim am Rhein, Germany; chemicals.oq.com) to study a proposed petrochemical project in Duqm, Oman. The project involves a world-scale steam cracker and derivatives units producing ethylene and propylene.

Arkema announces oleochemicals capacity expansion in Singapore

December 6, 2021 — Arkema S.A. (Colombes, France; www.arkema.com) announced a 50% global capacity expansion for its Oleris oleochemicals, which includes C7, C11 and C18 materials, comprising *n*-heptanoic acid, *n*-heptaldehyde, undecylenic acid and Esterol A. This new production capacity will be part of Arkema's previously announced biomaterials complex currently under construction on Jurong Island, Singapore. The new capacity is scheduled to come onstream in mid-2022.

Solvay to expand U.S. production of copper solvent-extraction products

December 2, 2021 — Solvay S.A. (Brussels, Belgium; www.solvay.com) plans to expand capacity at its Mount Pleasant, Tenn. facility in response to growing demand from mining operations for copper solvent-extraction (SX) products. Solvay expects the new capacity to be commissioned by the end of 2022.

PPG starts up coatings capacity expansion in Germany

December 1, 2021 — PPG (Pittsburgh, Pa.; www.ppg.com) announced the startup of expanded automotive coatings production at its facility in Erlenbach, Germany. The €3-million project nearly doubles the site's capacity. PPG acquired the Erlenbach site in 2019. The expanded clearcoat facility enables flexible manufacturing of multiple batch sizes of up to 25 metric tons (m.t.).

Nouryon starts up organic peroxides site in Tianjin

December 1, 2021 — Nouryon (Amsterdam, the Netherlands; www.nouryon.com) started full-scale production at its new organic-peroxide production site in Tianjin, China. Products manufactured at the site include Trigonox and Perkadox organic peroxides, as well as Butanox methyl ethyl ketone peroxide.

Lanxess to build new engineering-plastics production line in Changzhou

November 29, 2021 — Lanxess AG (Cologne, Germany; www.lanxess.com) will build a second compounding line for engineering plastics at its manufacturing site in Changzhou, China. An investment of around €30 million will increase the capacity in Changzhou by 30,000 m.t./yr. Together with existing facilities in Changzhou and Wuxi, this will bring the company's total compounding capacity in China to 110,000 m.t./yr. The new line is planned to go onstream in early 2023.

Styrolution to build advanced-recycling pilot plant for polystyrene

November 29, 2021 — Ineos Styrolution (Frankfurt am Main, Germany; www.ineos-styrolution.com) plans to construct a pilot plant for advanced recycling of polystyrene. The site will be set up in collaboration with Recycling Technologies in Swindon, U.K. It is expected to be operational in the second half of 2022. The Swindon pilot plant will be based on Recycling Technologies' fluidized-bed reactor technology for polystyrene depolymerization.

BP to build large-scale green-hydrogen plant in the U.K.

November 29, 2021 — BP plc (London; www.bp.com) is planning a new, large-scale "green" hydrogen production facility in the northeastern region of the U.K. that could deliver up to 500-megawatt electrical input (MWe) of hydrogen production by 2030. To be developed in multiple stages, the HyGreen Teesside project is expected to start production by 2025, with an initial phase of 60 MWe of installed hydrogen production capacity.

Mergers & Acquisitions

Trinseo to acquire European plastics recycling firm Heathland B.V.

December 8, 2021 — Trinseo (Berwyn, Pa.; www.trinseo.com) agreed to acquire Heathland B.V., a plastic waste collector and recycler based in Utrecht, the Netherlands. Heathland is focused on converting post-consumer-recycled (PCR) and post-industrial-recycled (PIR) polymethyl methacrylate (PMMA), polycarbonate (PC), acrylonitrile butadiene styrene (ABS), polystyrene (PS) and other thermoplastic waste.

Ascend to acquire compounding facility in Mexico

December 8, 2021 — Ascend Performance Materials, LLC (Houston; www.ascendmaterials.com) plans to purchase a compounding facility for engineered materials in San Jose Iturbide, Mexico, growing its global footprint and expanding production capacity. The purchase agreement includes the assets of DM Color Mexicana, a joint venture between Dainichiseika and Mitsubishi Corp. The deal is expected to close in the second quarter of 2022.

ExxonMobil acquires materials science specialist Materia

December 8, 2021 — Exxon Mobil Corp. (Irving, Tex.; www.exxonmobil.com) announced that its chemical company has acquired Materia, Inc. (Pasadena, Calif.; www.materia-inc.com). Materia developed technology for manufacturing a new class of materials that can be used in wind turbine blades, electric vehicle parts, sustainable construction materials, anticorrosive coatings and more. The acquisition includes Materia's technology center in Pasadena and its manufacturing facility in Huntsville, Tex. ExxonMobil intends to operate Materia as a wholly owned affiliate.

Saint-Gobain to acquire GCP Applied Technologies

December 6, 2021 — Saint-Gobain S.A. (Courbevoie, France; www.saint-gobain.com) entered into a definitive agreement to acquire all of the outstanding shares of construction chemicals manufacturer GCP Applied Technologies, Inc. (Cambridge, Mass; www.gcpat.com) in a transaction valued at around $2.3 billion. The transaction is expected to close by year-end 2022.

Celanese completes Santoprene acquisition

December 2, 2021 — Celanese Corp. (Dallas, Tex.; www.celanese.com) completed the acquisition of the Santoprene TPV elastomers business of ExxonMobil. As part of the transaction, Celanese has acquired two world-scale production facilities in Pensacola, Fla. and Newport, Wales with over 190,000 m.t./yr of total production capacity.

Cabot to sell Purification Solutions business for $111 million

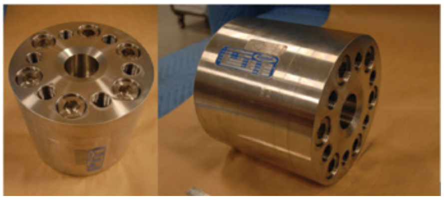
November 29, 2021 — Cabot Corp. (Boston, Ma.; www.cabotcorp.com) entered into an agreement to sell its Purification Solutions business to private equity firm One Equity Partners in a transaction valued at $111 million. Cabot's Purification Solutions business is focused on activated carbon products used in a range of environmental, health, safety and industrial applications.

Westlake to acquire Hexion's epoxy business for $1.2 billion

November 29, 2021 — Westlake Chemical Corp. (Houston; www.westlake.com) has entered into an agreement with Hexion Holdings Corp. (Columbus, Ohio; www.hexion.com) to acquire Hexion's global epoxy business for approximately $1.2 billion. Based in Rotterdam, the Netherlands, Hexion's epoxy business manufactures specialty resins, coatings and composites for a variety of industries. This transaction is anticipated to be completed in the first half of 2022. ■

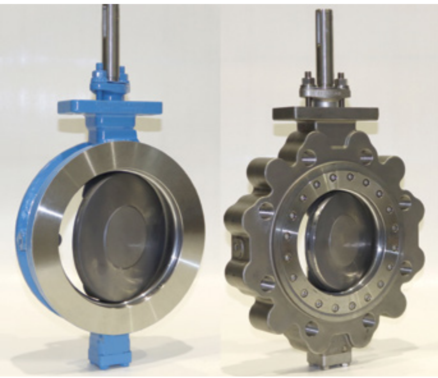
Mary Page Bailey

Focus on Valves



Conval

Circor International



Neles

Coperion K-Tron Salina

A check valve for urea service

A new in-line, axial check valve (photo) for urea and ammonia service was recently introduced. The new axial check valve complements this company's extensive urea service product line, which includes Clampseal Y-, T- and angle-pattern globe valves, Swivldisc gate valves and Camseal top-entry ball valves in ASME Class 900 to 2500 ratings. Standard sizes range from 0.5 to 6 in., with flanged, butt-weld, hub, lens-ring or custom connections. All of this company's urea-service valves are available in many alloys, including 316L Urea Grade, Ferralium 255, 310 MoLN, Duplex F51, Super Duplex F53, 25-22-2 SS, Zeron 100 and Titanium. Features include B16.34 design; integral gland wrench for concentric 360-deg packing load; in-line renewability; exceptional life cycle value; two-year warranty; standard helium leak testing; optional steam jacketing. — *Conval, Enfield, Conn.*
www.conval.com

This smart linear actuator has a high range of force output

The RTK REact EQ-L electric intelligent linear actuator (photo) is ideal for processes that depend on 100% running time, including industrial, chemical and power applications. Corrosion-resistant variants have been specially designed for offshore applications. The REact EQ-L electric actuator offers an all-in-one package for applications with opening/closing forces from 15 to 30 kN (3,380 to 6,750 lbf). The REact EQ-L opens the door for Industry 4.0 functionality and flexibility for multiple signal-exchange systems in open digital protocols for process automation. Outfitted with the optimized REpos digital positioner, the actuator offers data logging functions and remote control through Profibus or CANopen. The RTK REact EQ-L is also equipped with a mechanical fail-safe and emergency closing unit (ECU) function. The fail-safe can close the valve on loss of external power. The ECU is a function of the actuator that is designed to perform a closing operation in an emergency, such as when the temperature or pressure limiter is triggered. The actuator automatically returns to normal operation after a fail-safe or ECU function occurs. — *Circor International, Inc., Burlington, Mass.*
www.circor.com

This new butterfly valve range is versatile

A recently introduced butterfly valve product range (photo) enables easy valve configuration for a wide range of applications, including high-cycling valves to handle high-purity gases, and valves for abrasive service or corrosive media. The modular valve range enables a large number of configurations with the company's Neldisc metal seat and Jamesbury WaferSphere soft seat. The cross-compatible components and standardized parts make it easy to upgrade valve performance without the need to replace the entire valve. The butterfly valve range offers longer-lasting tightness, lower torque need, less wear and high flowrate, compared to predecessors. — *Neles Corp., Helsinki, Finland*
www.neles.com

This rotary valve is designed for chemical applications

The ZXD Blow-Through Premium rotary valve (photo) is designed to convey powder and granular products (smaller than 1 mm). The ZXD includes patented blow-through channel for optimal pocket sweeping, and offers pressure differentials up to 1.5 bar(g). Standard operating temperatures range up to 100°C — special configurations can be supplied for higher temperature (to 150–220°C). Heavy-duty design includes an explosion-pressure shock-proof rating of 10 bar(g). The valve is available with standard TEFC, EXP, Washdown, and IEEE Severe Duty gear motors. The ZXD comes standard with air-purged seals completely mounted with plastic or stainless-steel tubing, solenoid, filter regulator

and gage. Sealed-For-Life outboard shaft-seal arrangement separated from product by an air-purge seal and a drop-out opening. — *Coperion K-Tron Salina, Inc., Salina, Kan.*
www.coperion.com

Industry's first complete SIL 3-certified valve assemblies

These Fisher Digital Isolation final-element solutions (photo) meet the design process requirements of safety integrity level (SIL) 3 per the IEC 61508 standard, making them suitable for shutdown valves in critical safety instrumented system (SIS) applications. Without this solution, users must specify all the individual valve components, procure each one, and assemble it into a working whole. Even if these steps are done correctly, this type of custom assembly will still not provide all the benefits of the Digital Isolation assembly, says the company. The various components are specifically selected to satisfy the application requirements. The entire assembly is sold as a fully tested and certified unit, with a single serial number and associated documentation delineating the details of every part of the assembly. — *Emerson, Marshalltown, Iowa*
www.emerson.com

This valve assembly offers low cost and maintenance

The Double Dump Valve Assembly (photo) is said to be a low-cost and low-maintenance alternative to the traditional rotary airlock feeder, and provides a positive seal that can accommodate either full vacuum or pressure up to 100 psig. The air-operated seat inflates to provide a long-lasting, high-integrity seal and easily handles high cycling of dry granular or fine powdered materials. The seat automatically compensates for wear when it inflates against the disc, extending valve life considerably, the company says. The Double Dump Valve Assembly is available in carbon steel and stainless steel in sizes from 2- to 30-in. diameter and in any desired length. Other materials of construction are available upon request. — *Posi-flate, St. Paul, Minn.*
www.posiflate.com

This device prevents metal contamination of rotary valves

The RotaSafe RS1 valve-rotor protection system (photo) was developed to protect food, pharmaceutical and other ingredients from metal particulate contamination. The device continuously monitors rotary valve operation, automatically detects contact between the rotor and housing and, in the event of detection, immediately shuts down power to the drive motor to stop the process. The rotary airlock safety system is triggered before the powders or other bulk materials can become contaminated by foreign matter and before the valve incurs any damage from metal to metal contact. — *Gericke USA, Inc., Somerset, N.J.*
www.gerickegroup.com

This thermoplastic butterfly valve improves performance

The new 565 butterfly valve (photo) valve is said to be strong yet lightweight. It consists of high-performance plastic components that include polyvinylidene fluoride (PVDF) disc with fiber-reinforced polyamide housing and ethylene propylene diene monomer (EPDM) rubber or FKM (Viton) seals, making it ideally suitable for pressures up to 16 bars and temperatures ranging from –10 to 80°C. Available in sizes from NPS 2 through 12 (DN50-300), the 565 valve is 60% lighter than a comparable metal valve, allowing a single technician to safely and easily handle it during installation. The valve offers high corrosion resistance, long service life and more effective use of energy and resources during industrial production, says the company. — *Georg Fischer LLC, Irvine, Calif.*
www.gfps.com/us

Solids-handling diverter valve has new features

The second generation of the PT45 Diverter Valve (photo) introduces new features, such as adjustable alignment stops located in the housing, position indication from the tunnel itself, additional actuation options and external tunnel-position indication. A positive food-grade rubber silicone seal at each port is designed to help prevent contamination. Additional features include 45-deg port-to-port rotation, a two-way switching capability for either dilute-phase or dense-phase conveying applications, cast iron or aluminum housing, tunnel, and end plates with a 316 stainless-steel actuator and arm assembly, and inlet and outlet ports flanged to mate 150# ANSI flange patterns. Also included are a pneumatic actuator providing a 2–4-s actuation

Emerson

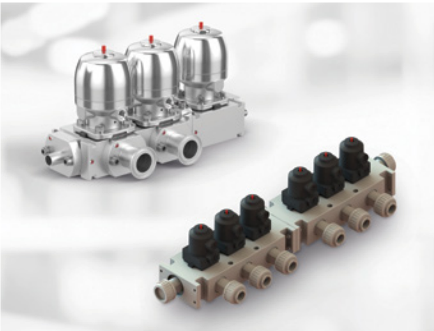
Posi-flate

Gericke USA

Georg Fischer

Schenck Process

Rembe



GEMÜ Gebr. Müller Apparatebau

Gardner Denver High Pressure Solutions (GD)

Val-Matic Valve and Manufacturing

time between ports, a four-way double solenoid air control valve with a NEMA 4 enclosure and a NEMA 4/4X position proof switch with two DPDT switch elements. High-temperature designs, electric actuators and cast 316 stainless steel housing, tunnel and end plates are also available options with the new version of the PT45 Diverter Valve. — *Schenck Process, Whitewater, Wis.*
www.schenckprocess.com

A passive isolation valve for explosion safety

The Ventex Passive Explosion Isolation Valve (photo) isolates interconnected equipment to prohibit the propagation of an explosion. It has a very robust design that is certified to handle organic dusts, metal dusts, hybrid mixtures and gases with one-way or two-way acting systems. The function of this passive isolation valve is very simple. During normal operation, air flows through the valve and passes around the poppet on the inside. During an explosion, the poppet is forced shut by the explosion pressure wave and locked into place. This creates a seal in the process line and effectively prevents the spread of flames and pressure. Additionally, there are signaling devices included on all valves to indicate an explosion has occurred. — *Rembe Inc., Fort Mill, S.C.*
www.rembe.us

Modular diaphragm valve with flexible connection system

The new P600S multi-port valve block (photo) allows for flexible combination of standardized single components. The new modular system therefore offers advantages regarding procurement and inventory-keeping, while simultaneously ensuring achievement of highly individual actuator travel and flow paths. P600S is available in various plastics, as well as stainless steels. With the plastic series, the company provides a multi-functional solution for blending, diverting, draining or feeding chemically corrosive media. The modular M-block diaphragm valve is available in materials PP-H and PVC, and in nominal sizes DN 8 to DN 25. Spigots, threaded sockets and union ends on the basic body can be adapted to individual requirements via the flexible connection system. The stainless-steel series is suitable for blending, diverting, draining or feeding demanding media in the pharmaceutical, biotechnology and food industries. The modular M-block diaphragm valve is available in various stainless-steel materials, and in nominal sizes DN 20 to DN 25 — other versions are available on request. Spigots, flanges and clamps on the basic body can be adapted to individual requirements via the flexible connection system. — *GEMÜ Gebr. Müller Apparatebau GmbH & Co. KG, Ingelfingen-Criesbach, Germany*
www.gemu-group.com

A valve to improve hydraulic fracturing performance

This company has proven in field trials that its new V3 valve (photo) significantly increases performance hours in high-pressure hydraulic fracturing operations. GD Redline valves and seats are designed for maximum performance and reliability, with the full-open, bonded design providing optimal flow efficiency and maximum sealing. The V3 valve has undergone a complete redesign to improve metallurgy and heat treatment resulting in enhanced wear resistance and strength. During field trials in the Eagle Ford, Permian and Marcellus shale plays, increased performance of up to 46% over the leading competitor was observed. In the Permian basin, performance of the V2 and V3 could be compared, with an increase in performance of 81% witnessed. — *Gardner Denver High Pressure Solutions (GD), Houston*
www.gardnerdenverpumps.com

All types of check valves to match the application

This company offers a variety of check valves (photo) to meet the needs of a given application — from potable water to abrasive slurries and corrosive chemicals. A wide range of metallurgies, seating materials and accessories are available. The importance of slamming characteristics, headloss and maintenance needs have been taken into consideration when designing these check valves, which are highly engineered to provide long life and trouble-free performance, the company says. All check valves are certified NSF/ANSI 61 for drinking water and NSF/ANSI 372 Lead-Free. — *Val-Matic Valve and Manufacturing Corp., Elmhurst Ill.*
www.valmatic.com ■

Gerald Ondrey

This bulk-bag filler has a built-in densification system

This company's four-post bulk-bag filler system (photo) features heavy-duty tubular carbon-steel frame construction for strength and durability. It is adjustable for future bag size flexibility. A food-grade inflatable spout seal assures a dust-tight seal to the bag inlet. The unit is equipped with a heavy-duty flat-top densification system with twin electric vibrators and a pallet-retaining system. The adjustable, high-output densification system quickly settles products, maximizing fill volume and enhancing bag stability. A gain-in-weight carbon-steel scale system with a 2,500-lb capacity, along with the densification system, are programed and monitored using a remote NEMA 4 control panel with a PLC, HMI and emergency stop pushbutton. — *Material Transfer & Storage, Inc., Allegan, Mich.*
www.materialtransfer.com

Rugged industrial lighting with efficiency benefits

The new Strongex range of industrial luminaires (photo) is designed specifically for installation in the oil, gas and petrochemical industries. Available for EX Zone 1 or EX Zone 2 applications, the Strongex 1 and Strongex 2 luminaires are said to reduce energy consumption, extend lifecycle and lower maintenance costs. Luminaire housings are made of polymethyl methacrylate (PMMA) and are 100% recyclable. Modules are available with smart sensors to further increase efficiencies. Strongex devices have IP66/IP69K and IK10 ratings and are resistant to both impacts and chemicals, protecting them in harsh installation environments. They also have a special seal that makes them completely gas-tight, protecting units from any atmospheric gases that could damage the electronics. — *Zalux, S.A., Zaragoza, Spain*
www.zalux.com

Blowers and compressors installed in ISO containers

Whether 20 or 40 ft, ISO containers have the advantage of being standardized, easy to stack, statically self-sufficient and are available with effective sound insulation. This company now combines these features with its blower and compressor technology (photo). The high power density of, for example, 24,000 m³/h compressed air per container with three Turbo AT 200-0.8 systems ensures versatile application possibilities per container unit in connection with a high control range. This aspect also facilitates placing the process air generation as close as possible to the demand. This shortens the distances, which subsequently leads to energy savings due to decreasing pressure losses. The container solutions are suitable for all standard blower and compressor types from this company. — *Aerzener Maschinenfabrik GmbH, Aerzen, Germany*
www.aerzen.com

A reliable testing gage for pressure-safety valves

New XP2i digital pressure gages (photo) are designed specifically for testing and calibrating pressure-relief or pressure-safety valves. Once the valve opens, the XP2i detects the pressure drop and displays the maximum pressure that the gage ever reached before the drop. This value remains on the display until the technician clears it. The XP2i features three accuracy levels: 0.1% of reading; 0.05% of full scale; or 0.02% of full scale. The gages are available in ranges from vacuum to 15,000 psi and are fully temperature compensated from –10 to 50°C. All versions are ATEX, IECEx and CSA intrinsically safe. An optional datalogging upgrade allows the XP2i to collect and store up to 32,000 data points and easily download the results to a spreadsheet or protected PDF file. — *Crystal Engineering, an Ametek STC brand, San Luis Obispo, Calif.*
www.ametekcalibration.com

PLC-equipped pumping system enables enhanced control

DMK SmartPump systems consist of a pump with a programmable logic controller (PLC), which controls the system's highly advanced servo motor. Motor speed, power consumption and force feedback can be

Material Transfer & Storage

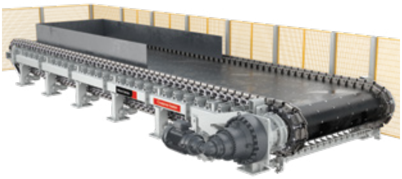
Zalux

Aerzener Maschinenfabrik

Crystal Engineering

Suncombe

ION Science



Metso Outotec

Andritz

Donaldson Filtration Deutschland

recorded by the PLC, and process information is collected and fed to the operator, who then has complete control of the process. Using that information, the PLC can automatically compensate for changes in the process due to changes in viscosity, pressure, temperature, particle size and so on. This allows the process to keep the flow relatively constant and pulse free. DMK SmartPump technology is able to monitor and measure pumping characteristics without having any sensors immersed in the liquid being pumped. Therefore, the DMK SmartPump technology allows for a vast array of liquids to be pumped without having to worry about sensor wear and tear. DMK SmartPump systems can pump nearly any size particle, with current models allowing for sizes up to 25 mm and future models exceeding 50 mm. In addition, the DMK SmartPump has been proven to pump high-viscosity fluids without the need for a bulk unloader and minimal head. The DMK SmartPump has been tested to pump fluids at pressures of up to 40 bars. — *Design Management Konsulting Oy, Kangasala, Finland*
www.dmkoy.fi

A new, low-volume biowaste-treatment system

The MicroEDS BioWaste Treatment System (photo) was recently introduced for biologically hazardous waste decontamination, typically required in the biopharmaceutical sector, laboratories and research institutes. The low-volume system is certified to ASME and ISO/EN standards for treating BSL 1, 2 and 3 waste using a batch process. MicroEDS includes a number of major technical advances, including thermal energy regeneration, low energy usage, 100% positive release for treated waste and electronic-records generation. The MicroEDS has been developed to fit into new lines or to be retrofitted into existing facilities. The system is designed to operate at a thermal treatment parameter of 121°C for 15 min, as well as variable temperature, time and F_0 lethality settings, for specific requirements. With capacities varied to suit a wide range of waste volume from 150 to 500 L/d, the MicroEDS is supplied with controls and interlocking functionality to ensure containment is constantly maintained and there is always a positive release prior to discharge of treated waste. — *Suncombe Ltd., Enfield, Middlesex, U.K.*
www.suncombe.com

Personal protection against H_2S exposure

The new ARA H_2S single-gas detector (photo) is designed to protect users from toxic levels of exposure to hydrogen sulfide. Classed as an item of personal protective equipment (PPE), the ARA H_2S is completely maintenance-free and offers continuous monitoring of exposure to H_2S levels. It offers a choice of display for users, either a lifetime countdown or concentration lifetime exposure, and it is possible to switch between the two, if desired. The ARA H_2S can also provide short term exposure limits (STEL) or eight-hour, time-weighted average (TWA) readouts for greater visibility into the overall health of a worker. Once activated, the ARA H_2S detector will continuously operate until the end of a two-year period, giving users appropriate warnings to source a replacement. There is also the option for a three-year lifespan model, which offers a hibernation mode, ideal for users who only visit the site on occasion. — *ION Science Ltd., Royston, U.K.*
www.ionscience.com

This hybrid feeder saves space and investment costs

The Crossover feeder (photo) is a hybrid feeding solution suitable for a wide range of greenfield and brownfield applications. Thanks to its innovative modular belt-over-apron design, the Crossover feeder is said to deliver unmatched levels of availability and reliability for bulk material transportation at lower overall costs. The Crossover feeder design features a reduced height of up to 50% as compared to conventional feeding technology. This lower height requirement provides an opportunity for capital investment savings by decreasing the excavation and civil works required. For retrofit applications, the reduced height profile allows the Crossover feeder economically replace existing

feeders, including apron or belt feeders, by lowering modification costs. — *Metso Outotec Corp., Helsinki, Finland*
www.mogroup.com

A new vacuum filter for maximum hygiene

Nutrion (photo, p. 16) is a new vacuum drum filter with a hygiene-optimized design that ensures high-quality end products for demanding sectors, such as food and pharmaceuticals. It features a self-emptying filter trough, a vapor-tight hood and advanced control options. Compared to traditional vacuum drum filters, the Nutrion vacuum filter has multiple improved features to eliminate any risk of contamination. Its filter trough is designed without any internal mechanical components and with self-emptying capability, simplifying the maintenance process and increasing cleanliness in this sensitive area. The vapor-tight hood eliminates the risk of contamination, with integrated nozzles for fully automatic cleaning in place (CIP), as well as optional cake washing. A magnetic clamping eliminates dirt traps and reduces downtime for filter cloth changes. For pre-coat applications, product quality and safety are also enhanced by the addition of a pre-coat scraper with step motors, again with CIP and a fully enclosed design. Nutrion comes with the proven Metris addIQ control system. The Nutrion filter has optoelectronic sensors for measuring cake height, as well as continuous trough-level measurement. — *Andritz AG, Gratz, Austria*
www.andritz.com

This system turns compressed air into safe breathing air

The Ultrapure Smart ALG breathing-air system (photo, p. 16) processes compressed air into safe breathing air, using a sequence of filtration and adsorption operations. A first stage removes condensate and particles from compressed air by an UltraPleat coalescence filter. Air is then guided through a desiccant cartridge to remove water and CO_2. Adsorption and regeneration alternate between two cartridges. Traces of CO_2, SO_2 and NOx are removed by adsorption, and CO is catalytically converted. A final filtration removes particles down to 0.01 µm, producing highly purified breathing air. The system is suitable for applications involving exposure to dust or solvents, and in the chemical and pharmaceutical industries where gases and contaminated aerosols are involved. — *Donaldson Filtration Deutschland GmbH, Haan, Germany*
www.donaldson.com

Open-path gas detectors warn workers of hazards

Emerson

This company has launched two open-path gas detectors (photo) that operate in extreme environments, including heavy vibration conditions and operating temperatures ranging from –55 to 65°C. The Rosemount 935 combustible gas detector uses infrared (IR) technology to detect a wide range of highly combustible hydrocarbon gases, including methane, propane and ethylene. The Rosemount 936 toxic gas detector uses ultraviolet (UV) technology to detect H_2S and ammonia — two of the most common toxic gases in industrial facilities. Leveraging xenon flash technology, the Rosemount 936 enables greater installation flexibility versus the tunable diode laser (TDL) technology, which needs perfect alignment between beam and receiver for high reliability. With nearly twice the tolerance for misalignment than TDL, users can save up to 30% of installation time and streamline project schedules, says the company. — *Emerson, Shakopee, Minn.*
www.emerson.com

ECOM Instruments

SensoTech

Quattroflow

Leybold

Smart glasses for industrial use in hazardous areas

Together with its cooperation partner Iristick, this company is introducing Visor-Ex 01 smart glasses (photo) — the intelligent wearable that combines high camera quality and reliable communication features in an ergonomic design. The device enables workers to perform all tasks that require hands-free use, as well as communication, in hazardous areas. This can include many digital workflows, such as maintenance procedures under the guidance of a remote support expert, who can give instructions and guidance with precision seeing what is happening through the eyes of the technician. The intrinsically safe smartphone Smart-Ex 02 as a computing unit, combined with a pocket unit with replaceable battery for power supply, creates an intelligent ecosystem for a wide range of applications. Visor-Ex 01 will be certified according to ATEX/IECEx Zone 1/21 and 2/22, as well as EC/CEC Division 1 and 2 and will have protection class IP68. It can be used in a temperature range from –20 to 60°C. — *ECOM Instruments GmbH, Assamstadt, Germany*
www.ecom-ex.com

Bringing AI operational management to the water industry

CREA is an operational intelligence platform that allows management and optimization of integral wastewater treatment processes using real-time data monitoring of key process parameters. CREA provides intelligent decision support, multiple control strategies and automatic reporting on key data analytics and achieves quality consent limits with reduced operational costs and enhanced reliability. The software incorporates classical mathematical models, fuzzy logic, pattern recognition, machine learning and artificial intelligence (AI) algorithms to analyze real-time data and provide control strategies and decision support dashboards. Key wastewater treatment applications, such as aerobic and anaerobic processes, nutrient removal, anaerobic ammonium oxidation (anammox), sludge digestion and dewatering, can be optimized from the platform. — *Te-Tech Process Solutions Ltd, Southampton, U.K.*
www.te-tech.co.uk

Smart monitoring of oil concentration in the refrigerant circuit

LiquiSonic OCR (photo) provides precise real-time readings — without sampling — of oil concentrations in refrigeration lines. The determination of the oil concentration is based on pressure, temperature and sonic velocity measurements in the liquid refrigerant. This measuring principle enables highly accurate and fast adjustment of the desired oil-refrigerant ratio. Because the system monitors in real time, the user continuously has precise knowledge of the ratio of oil and refrigerant. Numerous product data sets (calculation models) can be stored in the controller of the measuring system. This makes it possible to monitor a wide range of refrigerants. The system provides maintenance-free operation and comprehensive documentation options. — *SensoTech GmbH, Magdeburg–Barleben, Germany*
www.sensotech.com

A new multiple-use pump for biopharmaceutical applications

New QF5k quaternary (four-piston) diaphragm pumps (photo) incorporate a variety of critical design enhancements and offer a maximum flowrate of 6,000 L/h, making them suited for demanding biopharmaceutical applications, such as chromatography, virus filtration, sterile filtration and depth filtration. QF5k pumps feature pump chambers that provide drainability to maximize product recovery, while significantly improving venting to remove entrapped air during priming. Available in four different drive versions, QF5k pumps were developed to meet a wide range of process requirements — from integration into fully automated systems to stand-alone applications that require their own pump controller. Additional features and benefits include: a proportional and linear flow performance for optimal precision during flow control; 120:1 turndown ratio; high flow stability even at low flowrates; low-pulsation characteristics; risk-free dry running; and clean-in-place (CIP)/steam-in-place (SIP) and autoclave capabilities. The QF5k model can also be integrated

with the new Q-Control integrated pump controller to provide users with automated control over their pump operations. — *Quattroflow, part of PSG, a Dover company, Duisburg, Germany*
www.quattroflow.com

A small, high-vacuum system for laboratories and research

TurboLab Core (photo, p. 18) is a small plug-and-play high-vacuum pumping system for research and laboratory and industrial applications. The ergonomic system includes the oil- and maintenance-free Turbovac i turbomolecular pump, the Divac 1.4 dry diaphragm backing pump and a simple controller, which can also serve as a speed and pressure display. Within the TurboLab series, the compact tabletop unit fills the gap for entry-level vacuum needs that require a clean, dry, stable source of high and ultra-high vacuum. The pumping station frame stands on rubber feet to prevent the transmission of vibrations. This is important when the system is placed close to a microscope or other precision laboratory equipment. — *Leybold, a part of Atlas Copco's Vacuum Technique, Cologne, Germany*
www.leybold.com

Single-use separator for the biopharmaceutical industry

The new kytero single-use separator (photo) is designed for obtaining fermentation solutions and cell cultures, and is equipped with the

GEA

Westfalia Separator disk-stack technology for maximum yield, high separation efficiency and gentle product handling. The kytero combines the high performance of larger stainless-steel pharmaceutical centrifuges with the features and benefits offered by disposable separation. The mobile plug-and-produce unit also fits into any clean room. All elements in contact with the product, such as hoses and containers, are made of recyclable material and are replaced after use. This prevents any cross-contamination and ensures hygienic harvesting of the cells. The elimination of CIP (clean-in-place) and SIP (sterilize-in-place) also eliminates the cost of chemicals and water, especially water-for-injection (WFI). In addition, the energy and labor required for cleaning and sterilization are eliminated. Setup and changeover time (only 5–10 min for preparation) is minimal. A 500-L batch of animal cells is processed in about four hours. — *GEA Group AG, Düsseldorf, Germany*
www.gea.com

An updated simulation platform for multilayer films

This company has launched version 5.0 of its proprietary Bonfire Film Development Platform for modeling and simulating multilayer films. A free tool for value-chain collaborators, this platform speeds up the development of sustainable flexible packaging by helping designers and engineers shortlist formulations and reduce the number of physical trials. Specifically, the platform helps converters achieve sustainability goals through material reduction (downgauging), transition from multimaterial laminates to recyclable polyethylene (PE) structures and closing the loop with post-consumer resin (PCR) incorporation. Version 5.0 adds several new modules and enhancements, including: laminations structure builder; sealant dashboard; molecular architecture dashboard; and more. — *NOVA Chemicals, Calgary, Alta., Canada*
www.novachem.com

Mary Page Bailey and Gerald Ondrey

Facts At Your Fingertips

Flexible Intermediate Bulk Container (FIBC) Basics

Department Editor: Scott Jenkins

Flexible intermediate bulk containers (FIBCs), sometimes known as bulk bags, are widely used in the chemicals, pharmaceuticals, food, agriculture and other chemical process industries (CPI) sectors, to transport and store dry, flowable bulk-solid materials, such as granules, powders, grains, clays, cement, resins and others. This one-page reference provides basic information on FIBCs to aid in their selection and use.

FIBC bag construction

Most FIBCs in use in the CPI are made of polypropylene extruded in threads or ribbons and interwoven in a longitudinal-and-transverse pattern. When filled, FIBCs can be handled by forklift trucks, cranes or hoists, and are designed to be lifted from the top by means of permanently attached lift loops, sleeves or stevedore straps.

Generally, FIBCs in use at industrial sites are one of the following types:

U-panel. U-panel bags have one panel forming two opposite sides and the bottom, creating a "U" shape.

Circular. A circular bag (also known as a tubular bag) is made from fabric woven on a circular loom that is then cut to the proper length for a specified bag height. This eliminates the vertical seams on each of the bag's sides.

Four-panel. Four separate pieces of fabric are sewn together to create the body of the bag.

Baffle. In a baffle bag, pieces of fabric or other material are sewn across each corner of a tubular or four-panel bag to help stabilize the load and more efficiently utilize storage or shipping space.

Linings. FIBCs can be used with or without liners. Two common liner types are form-fit and tubular. Form-fit liners will allow improved filling and complete discharging of product. Tubular liners are straight cylinders that may have one end heat-sealed.

FIBC selection and use

FIBCs are lightweight (5–7 lbs), offering a low package-to-product weight ratio and the ability to hold one metric ton of product. With a standard filled diameter of 45–48 in., FIBCs are designed to fit two across in a truck or a shipping container, although specially configured containers are available (Figure 1).

To ensure that an FIBC will meet the requirements for handling a specific product, users should seek to answer the following questions on product details:

- What is the product's bulk density (lbs/ ft^3 or kg/m^3)?
- What is the safe working load (SWL; the amount of load that a FIBC is designed to carry) and the net fill weight needed per FIBC?
- Is the product considered a hazardous material or dangerous good?
- Does the FIBC need to meet pharmaceutical or food-safety requirements?
- What is the product's mesh size (particle size)?
- What is the product's moisture content?
- Are there special barrier needs (is the product hydroscopic, for example)?
- What are the product's flow characteristics (free-flowing, dust-forming, bridging, static buildup)?
- What is the filling temperature?
- What are the product's sensitivities to agglomeration, clumping, mechanical deformation, vibration?

FIBC safety

Handling FIBCs involves safety considerations, including the following:

Load. The SWL is determined by the design of the FIBC, along with the sewing method used and the strength of the fabric.

Antistatic. FIBCs made from plain woven polypropylene and other non-conductive materials (Type A FIBCs) offer no static protection. Type B FIBCs are made from plain woven polypropylene fabrics that have a low breakdown voltage to prevent the occurrence of highly energetic propagating brush discharges that can ignite a dust-air mixture, according to ABC Polymer Industries, a maker of FIBCs. However, Type B FIBCs do not have any mechanism for dissipating static

FIGURE 1. FIBCs have a standard filled diameter of 45–48 in. and are designed to fit two accross in a truck or shipping container

electricity. Type C FIBCs are made from non-conductive polypropylene fabrics interwoven with conducting threads, normally sewn in a grid pattern, that connect the bag to ground via a grounding point. Type D FIBCs are made from antistatic and static-dissipative fabrics that are designed to safely prevent the occurrence of incendiary sparks, brush discharges and propagating brush discharges without the need for a connection from the bulk bag to the ground. Type D FIBCs are designed to safely package combustible products and to handle products in combustible and flammable environments.

Stacking. FIBCs should only be stacked if they are designed to be stacked, if their stability is assured and if they are stacked using a "pyramid" or "supported" stacking method. In pyramid stacking, each bag above the first layer must sit on at least four lower bags. Each layer is subsequently tiered inward, forming a pyramid structure. Supported stacking refers to placing FIBCs against two retaining walls of sufficient strength.

Filling and unloading. Filling and discharging options are shaped by the filling method (conveyer, gravity, bulk bag filler), clearance, desired fill rate, discharge method (gravity, screw, conveyor, bottom cut, full dump) and whether or not controlled discharge is required, as well as whether bag handling is available. ■

Refences

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Production of Ethylene from Ethane

By Intratec Solutions

Ethylene is used almost exclusively as a building block — it is the largest-volume petrochemical produced worldwide (Figure 1). Production of ethylene grew rapidly in the middle of the 20th century, when oil and chemical companies began separating it from petroleum refinery waste gas and producing it from natural gas and ethane (obtained from byproduct refinery streams).

Ethylene is mostly used as a raw material for the production of polymers and other organic chemicals in consumable end uses, especially packaging. Polyethylene (PE) is responsible for about 60% of global ethylene demand. The main class of PE produced in the world is high-density polyethylene (HDPE), which is responsible for the consumption of one-third of the available ethylene. This is followed by low-density polyethylene (LDPE) and linear low-density (LLDPE) varieties.

Ethylene is stored as a liquid under high pressure or at low temperatures. However, most of the time, ethylene is directly supplied to consumers, via pipeline grids.

Steam cracking

Steam cracking — high temperature pyrolysis in the presence of steam — is the main technology used to make ethylene. The petroleum-based feedstocks used in steam cracking are grouped as gaseous (ethane, propane, *n*-butane, natural gas liquids and any mixture of them) and liquid (field condensates, natural gasoline, benzene, toluene, xylenes, raffinate, naphtha). Different feedstocks and cracking conditions generate different product slates. In general, high yields of ethylene with small amounts of byproducts are obtained from gaseous feedstocks, while lower ethylene yields with larger amounts of byproducts are obtained from cracking liquid feedstocks.

Process

Production of polymer-grade (PG) ethylene from ethane feedstock can be divided in three main parts: cracking and quenching; compression and drying; and separation (Figure 2).

Cracking and quenching. Ethane and dilute steam are fed to furnaces in which, under high-severity conditions, ethane is cracked, forming ethylene and some byproducts. The furnace outlet stream is subsequently fed to a water-based quench, to prevent further reactions and formation of undesirable byproducts. From the quench tower, the cracked gas is directed to compression and drying.

Compression and drying. The compression of the cracked gas is performed across five stages. After the third stage of compression, carbon dioxide and sulfur are removed from cracked gas by caustic soda and water washes in a caustic scrubber.

Separation. After caustic wash, the cracked gas is sent to a fourth compression stage and then fed into a column for removing C3+ hydrocarbons. The overheads product from this column, composed primarily of ethylene and ethane, is fed to the last compression stage. The compressed gas is fed to an acetylene converter and then to a cold box for hydrogen and light hydrocarbons removal, ensuring that ethylene losses are minimal. At this point, the product from the chilling train is fed to two further separation columns. In the first column, methane is obtained from the top and further used in the cold box, while the bottom stream is fractionated in the C2-splitter. In this column, high-purity ethylene is drawn from the column as a side stream. Ethane, from the C2-splitter bottom, is recycled to the cracking furnaces.

$H_2C{=}CH_2$

Ethylene Molecule

FIGURE 1. Ethylene is the most produced petrochemical worldwide, by volume

Economics

Most recently, growing environmental concerns have increased interest in alternative routes to conventional petroleum-based ethylene production, especially the dehydration of bio-derived ethanol. With such a diverse range of derivative products, ethylene demand is highly sensitive to economic cycles. In fact, it is often used as a reference in the performance evaluation of the petrochemical industry. The economics of ethylene production is largely dependent on the prices for feedstocks and co-products (mainly propylene). In general, heavier feeds lead to higher production costs and capital investment required. ■

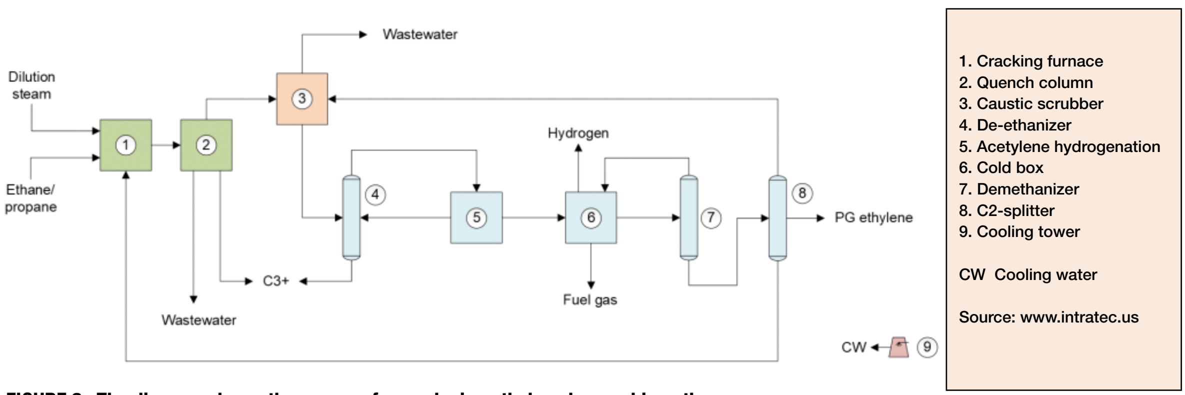

FIGURE 2. The diagram shows the process for producing ethylene by cracking ethane

Editor's note: The content for this column is developed by Intratec Solutions LLC (Houston; www.intratec.us) and edited by *Chemical Engineering*. The analyses and models presented are based on publicly available and non-confidential information. The content represents the opinions of Intratec only.

Process Commercialization:

The 2021 Kirkpatrick Chemical Engineering Achievement Award

IN BRIEF

HALDOR TOPSOE

BQE WATER

DOW DEUTSCHLAND

DOW INDUSTRIAL INTERMEDIATES & INFRASTRUCTURE

SAPPHIRE TECHNOLOGIES

To honor the efforts of those chemical engineers and their companies that have successfully commercialized a new process for the first time, *Chemical Engineering* magazine has been bestowing its Kirkpatrick Chemical Engineering Achievement Award since 1933.

The aim of the Award is to recognize and honor the most noteworthy chemical-engineering technology commercialized anywhere in the world during the two years prior to a given award year. The results for the 2021 Kirkpatrick Chemical Engineering Achievement Award are as follows:

Winning Award

- Haldor Topsoe A/S (Lyngby, Denmark; www.topsoe.com), for its hydrotreating catalyst TK-6001 HySwell (Figure 1)

Honor Awards

- BQE Water (Vancouver, BC, Canada; www.bqewater.com): Selen-IX Technology
- Dow Deutschland Anlagengesellschaft mbH (Walsrode, Germany; www.dow.com): Walocel Cellulose-Ether Product
- Dow Industrial Intermediates & Infrastructure (Midland, Mich.; www.dow.com): Syntegra Solvent-Free PU Dispersion
- Sapphire Technologies (Cerritos, Calif.; www.sapphiretechnologies.com): FreeSpin Turboexpander Generator

These companies join the long and distinguished roster of past winners, which includes such milestones as LanzaTech for Emissions-to-Ethanol Fermentation Technology (2019); CB&I and Albemarle Corp. (2017), for the AlkyClean process — the world's first solid catalyst alkylation process; Lucite International for its Alpha process for making methyl methacrylate (2009); Cargill Dow LLC for its production of thermoplastic resin from corn (2003); Monsanto hollow-fiber membranes for gas separation (1981); Union Carbide low-pressure low-density polyethylene (1979); M.W. Kellogg single-train ammonia plants (1967); the U.S. synthetic rubber industry (1943); and Standard Oil Development Co. aviation fuels (1939). A complete list of all past winners can be found at: www.chemengonline.com/kirkpatrick-award.

Although the staff of *Chemical Engineering* organizes and bestows the award, neither the editors nor others associated with the magazine play any role in the selection or judging of the winner. Instead, the winner is selected by a Board of Judges (BOJ) comprised of current chairs of chemical engineering departments at accredited U.S. and E.U. universities (box below). The members of the BOJ are, in turn, selected by chemical engineering department chairs of accredited U.S. and E.U. universities. It is this unbiased selection process, combined with a more than 88-year tradition that makes the Kirkpatrick Award one of the most prestigious honors that a chemical process industries (CPI) company can receive.

This article presents more details about the process technologies honored in 2021.

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WINNING ACHIEVEMENT
Haldor Topsoe: TK-6001 HySwell™ catalyst

Today, petroleum refiners globally must comply with ultra-low sulfur fuel legislation, and for commercial reasons, they aim to maximize production of gasoline, jet and diesel fuels. This results in tremendous demand for absolute top-tier nickel and molybdenum-based catalyst (NiMo) for ultra-low sulfur diesel (ULSD) or hydrocracker pretreat reactors.

Another driver is the availability of low-cost hydrogen. When catalytically added to middle distillate fractions, hydrogen increases the liquid volume swell and produces higher volumetric yields of valuable products. Consequently, a catalyst that maximizes hydrogen uptake into hydrocarbon streams becomes desirable. Particularly, a NiMo catalyst has high activity for such a mechanism.

Petroleum refiners need catalysts with the highest possible activity. Despite the tremendous improvements in catalyst technology over the past 20–30 years, refiners are still looking for the absolute best NiMo catalyst for their ULSD or hydrocracker pretreat reactors.

So far, only unsupported catalysts have had the required activity. However, unsupported catalysts are very costly and cannot be regenerated. With these factors in mind, Topsoe decided to develop an alumina-supported catalyst to deliver the required activity — the HySwell catalyst family.

Specifically, alumina-based hydrotreating catalysts will help minimize the operating cost when targeting volume swell. Furthermore, HySwell catalysts can be regenerated, and they utilize the active metals better, which drives down cost compared to bulk-metal catalyst formulations. This is clearly more sustainable. A target activity improvement compared to standard catalysts was set to 5–7°C, which is equal to 15–20%.

How it was done. By employing advanced microscopy, Topsoe researchers discovered how unique catalyst preparation techniques influence catalytic functions at the atomic scale. This led to the development of an improved alumina pore structure and optimization of the interaction between the active metals and the alumina support. As a result, Topsoe devised very active and stable CoMo/NiMo catalyst formulations.

The HySwell technology exploits this combination of higher concentration of active metals and optimized interaction to the highest degree yet. This unique technology combines the earlier BRIM and HyBRIM technologies with a new proprietary catalyst preparation step. As a result, it substantially increases the activity of both direct desulfurization/denitrogenation and hydrogenation sites without compromising catalyst stability.

FIGURE 1. Shown here is the winning team from Haldor Topsoe: Anders Bo Jensen, product line director; Lars Pilsgaard Hansen, principal scientist; Per Zeuthen, senior director; Magnus Magnussen, principal scientist; Frank Bartnik Johansson, R&D director

In 1984, Topsoe's pioneering researchers, led by Dr. Henrik Topsøe, published results showing that there was a modified Co-Mo-S structure with substantially higher activity per active site than traditional Co-Mo-S structures. The two structures were called Type I and Type II sites.

In the early 2000s, Topsoe's commitment to fundamental research in surface science paid off again, and a new activity site was discovered: the BRIM site. Using scanning tunneling electron microscopy (STM), researchers visualized these new activity sites and have been able to elucidate the catalytic mechanisms taking place.

The BRIM sites are located close to the edges on top of the Co-Mo-S (or Ni-Mo-S) slab structures. Here, the BRIM sites act, being metallic in nature, with the *pi*-electron clouds of the organo-sulfur reactants. This interaction draws the most difficult sulfur molecules in for the initial hydrogenation step, enhancing their ability to further interact with the nearby Type II sulfur vacancies.

Topsoe's HyBRIM technology was commercialized in 2013. It includes an improved production technique in which the BRIM technology is combined with a proprietary catalyst preparation step. This technique ensures better dispersion of active components on the surface of the support along with optimized metal-support interactions. Together, they facilitate both the formation of more active Type II sites and promote higher dispersion of the molybdenum slabs of Mo/Ni (Mo/Co).

Yet another step increase in activity is obtained through HySwell, which involves an improved production technique for NiMo hydrotreating catalysts. It combines the BRIM and HyBRIM technologies with a proprietary catalyst preparation step. Merging previous technologies with novel atomic-level insights enabled Topsoe to design a metal slab structure characterized by an optimal interaction between the active metal structures of even higher concentrations and the catalyst carrier. The activity of the Type II sites is positively influenced by the improved metal-support interaction.

HySwell technology exploits this combination of a much higher concentration of active metals and, in turn, a better Ni promotion of the sulfided molybdenum slabs through the optimized interaction. Thus, the activity of both direct desulfurization/denitrogenation and hydrogenation sites are substantially increased, without compromising catalyst stability. Ultimately, this increases both the hydrodesulfurization (HDS) and hydrodenitrogenation (HDN) performance of the catalyst.

Commercial production. During the catalyst development, and prior to the production at commercial scale, all the experimental catalysts have been tested and evaluated by use of advanced pilot plants, and products have been analyzed using cutting-edge analytical tools. After developing a successful and stable catalyst recipe, it was decided to

perform a commercial scale test involving production of typically 10–20 tons of catalyst. After just one well-planned test production at Topsoe's plant in Bayport, Tex., the company decided to commercialize this new high-performing catalyst.

Topsoe manufactures its own pseudo-böhmite, which is the raw material for the alumina support. This allows full control of the entire manufacturing process and coupled with tight quality control in manufacturing, it enables Topsoe to achieve the desired catalyst performance.

Since it was launched in 2019, Topsoe has achieved ten sales, with several already installed and performing excellently, according to the company. The TK-6001 HySwell has delivered up to an impressive 17°C improvement compared to the previous catalyst in a commercial unit.

HONOR ACHIEVEMENT

BQE Water
Selen-IX™ process

Responding to growing environmental issues associated with selenium pollution in the mining industry, BQE Water developed the Selen-IX technology as an industry-specific solution to manage the selenate form of selenium in wastewater. While selenium can be present in many chemical forms, selenate is the most prevalent and most difficult to remove.

Commercialized in 2020, Selen-IX represents a disruption in selenate treatment dominated by biological reduction systems by offering capabilities other systems cannot. Specifically, Selen-IX can:

- Meet end-of-pipe selenium limits <2 ppb without reliance on dilution
- Produce stable inorganic solid residue with off-take potential
- Remove selenate "selectively" from wastewater containing a cocktail of ions without adding any chemical reagent or constituent to the water that was not previously present
- Remove selenate without transforming any part of it into a more bioavailable form of selenium such as organo-selenium or selenocyanate
- Adjust rapidly to fluctuations in feed water flow and composition
- Operate intermittently with instant ramp up/down regardless of feed water temperatures

BQE Water

FIGURE 2. Shown here are the ion-exchange columns of the first industrial-scale Selen-IX plant

The Selen-IX process. The novelty underlying Selen-IX is the unique integration of ion exchange (IX) and electro-reduction (ERC) to remove selenate to levels well below North American selenium regulations that currently range from 1 to 10 parts per billion (ppb), while also eliminating the generation of a liquid brine waste that is associated with conventional IX and membrane treatments. A U.S. patent for Selen-IX was issued in 2018.

Selen-IX is comprised of two main unit processes. In the IX part of Selen-IX, non-selective strong base anion resins are used to selectively capture selenate from influent to produce regulatory compliant effluent for discharge into the environment. Once saturated with selenium, brine is used to elute selenium from the resin to enable its re-use in subsequent cycles, similar to conventional IX. A compelling feature of Selen-IX is the recycling of brine through ERC treatment. Recycling eliminates liquid waste typical of conventional IX and imparts selectivity to resins that are otherwise non-selective.

The purpose of the ERC process is to remove selenate from the brine down to levels enabling the brine to be re-used in the IX and to fix the selenium into stable non-toxic solids. At the heart of the ERC is an electrochemical cell that features a sacrificial iron anode similar to electrocoagulation (EC). However, unlike conventional EC that releases iron into solution to co-precipitate metals and metalloids without changing their valence, the ERC changes the selenium oxidation state from +6 to 0 to create a solid matrix that gives stability to Selen-IX solids with minimal risk of selenium re-release.

Development timeline. Development of Selen-IX began in 2012 at a bench scale in BQE Water's laboratory in Vancouver, Canada. Promising results garnered the attention of a coal producer. In 2013 a mobile pilot plant was constructed and the first pilot campaign to remove selenate from coal process waters was carried out. This project successfully achieved the objective of producing effluent containing <5 ppb selenium.

Further bench-scale development took place in 2014, followed by a second pilot campaign for a gold project in development. Selenium contamination of water was recognized as a key issue in the permitting of the project. Results of the pilot demonstrated selenium removal to <1 ppb and enabled the mine owner to satisfy an integral condition of their environmental assessment certificate.

A third and final pilot was completed at the end of 2015 for a copper and gold project. As part of the permitting requirements, Selen-IX was piloted to demonstrate the removal of selenium from mine water to <1 ppb. The results were in compliance with the site-specific regulations and enabled the mine owner to secure the necessary environmental permits to advance their project.

Throughout the many bench- and pilot-scale testing campaigns, progressively better process efficiencies were achieved which had the positive impact of reducing capital and operating costs for Selen-IX while producing effluent containing <1 ppb selenium.

Inaugural Selen-IX Plant. After the positive results from their pilot and the success of the industrial demonstration project, the copper and gold client made the decision to proceed with a full-scale Selen-IX plant (Figure 2). Located in Northern British Columbia, the capabilities of Selen-IX are perfectly suited for the requirements and conditions of this remote mine site where selenate is the main contaminant of concern.

Specifically, provincial regulators applied a <2 ppb end-of-pipe discharge limit for selenium. Due to its

northern location, large flows of cold water will require treatment seasonally. This necessitates a robust system with predictable operation and minimal upsets that can offer quick ramp-up following the spring freshet and quick turn-down prior to the freeze-up of water in fall.

Construction of the 1,000 gal/min capacity Selen-IX plant was substantially completed in fall 2019 but freezing temperatures delayed commissioning to spring 2020. Performance testing of the plant concluded in September 2020 and from there, the plant operated continuously at the maximum design flow, where it met performance expectations and produced effluent containing <2 ppb selenium.

HONOR ACHIEVEMENT

Dow Deutschland: Walocel™ M120-01

Cellulose ethers are vital additives for dry mortar cementitious-tile adhesives, because they help ensure mortars retain water, which is required for durable bonding between tile and substrate. The water-retention efficiency improves with increasing solution viscosity, which scales with polymer molecular weight. To be economical, the cellulose used to synthesize the polymer is preferably pulp from wood sources and thus the polymer chain length is limited by nature.

Launched in 2020, Walocel M120-01 Cellulose Ether is the first scaled commercial product obtained by long-chain branching. Overcoming nature's limitations in molecular weight is a step-change innovation compared to standard cellulose ethers, enabling dosage reduction in mortars by up to 25% without compromising performance.

Production process. Walocel cellulose-ether production involves cellulose grinding, batch-wise etherification, purification with hot water, drying and milling (Figure 3). Etherification of the cellulose is a three-phase heterogeneous reaction of cellulose, where surface area, solid-liquid volume ratio, and mixing speed are critically important. As the target was to long chain branch the high-molecular-weight cellulose chains without causing significant gelation, new process technology was needed. The challenge during the product development was to introduce the crosslinker into a well-established process and achieve its homogenous distribution resulting in high reaction yield and optimized batch run rates.

From polymer science literature it was known that long-chain branching reactions are probabilistic processes dependent on crosslinker concentration, crosslinker end-group reaction kinetics, and the parent polymer molecular weight distribution. The key is to promote the probability of a single graft between two parent chains versus other outcomes. While the simplest modeling conclusion is to use a very dilute crosslinker concentration, this does neither comprehend the myriad possible outcomes nor ensure a successful process or a viable production window.

Scaleup. After successful testing of first laboratory-scale high-molecular-weight prototypes, systematic process investigation focused on key reaction engineering variables started. At laboratory scale, dilute additions can be supported by high shear mixing rates; at production scale, this option is not possible. At laboratory scale, heats of reaction are more easily managed as the vessel surface area to volume ratio is large compared to production scale. Managing reaction heat and reaction pathways, while not significantly reducing run rates, is much more challenging. Other approaches to maximize crosslinker dispersion needed to be developed using analytical tools that enabled following post-reaction outcome versus process parameters. These efforts demonstrated a viable production process window that delivers water-soluble cellulose ethers confirmed by systematic in-house and users' mortars application tests.

Production-plant-scale implementation of Walocel M120-01 Cellulose Ether required design and

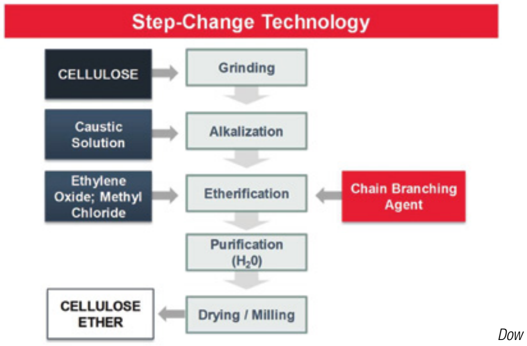

FIGURE 3. The production steps for producing Walocel cellulose-ether are shown here

installation of a tailor-made dosage system and changes to mixing speed and reactor solid-liquid volume ratios. The need for homogenous distribution of reactants in the heterogeneous reaction mixture and process safety requirements also impacted the design.

The combination of spray-nozzle design, understanding of the mixing behavior inside the ploughshare reactor depending on the filling level and swelling behavior of cellulose raw material during the process, process automation strategy and the measurement instrumentation were key engineering parameters for a successful and reproducible process development on plant scale. Without negative impact on the reaction itself, as well as the reaction temperature profile, the controlled crosslinking step using a bifunctional diglycidyl ether could be successfully added into the high-quality and highly cost-optimized cellulose ether reaction process.

The production of Walocel M120-01 Cellulose Ether required addition of a new reactive substance to an existing reaction process. Because cellulose ethers are produced under pressure and the final product is water washed to remove byproducts from etherification, any new reactant must be thoroughly studied for both reaction and environmental safety. To ensure the highest level of process safety, a stepwise process development combined with a structured management of change (MOC) process was applied. Once identified, suitable substance classes with low chemical hazards were evaluated in cooperation with Dow's Reactive Chemicals group

prior to laboratory-scale process development. Beginning with low crosslinker addition, the impact on the reaction was monitored for heat of reaction and byproducts.

The commercial-scale production of Walocel M120-01 Cellulose Ether has been running without incident since 2019 at a sold-out scenario of the production assets. So, the new process implementation required a tight implementation batch schedule as well as a low-risk approach to help minimize off-specification production.

HONOR ACHIEVEMENT

DowPolyurethanes Syntegra™ PU Dispersion

Due to its similarities with actual leather, microfiber leather has become the dominant replacement material for genuine leather in recent years. However, current processes for making microfiber leather have severe deficiencies. Syntegra Waterborne Polyurethane (PU) Dispersions are solvent-free dispersions that achieve high performance with an excellent sustainability profile. Microfiber leather manufacturers can use Syntegra Waterborne Polyurethane Dispersions in their existing processes to produce the most sustainable, high-quality microfiber leather available.

Presently, the most commonly used process of microfiber leather production is based on the polyurethane-in-dimethylformamide (DMF) solution approach. First, the pre-fabricated nonwoven sheet is impregnated into 25–35% PU-in-DMF solution, followed by washing with DMF-water mixtures to reduce the DMF content and microcellular structure generation. Then the formed intermediate sheet will be washed by toluene or sodium hydroxide aqueous solution to remove unnecessary fiber components to generate the "micro" fiber structure. Finally, the microfiber leather will be finished by drying. In the whole procedure, DMF is used due to its low viscosity, easy processability and porous structure generation.

However, DMF is classified as a Substance of Very High Concern by the European Chemicals Agency. The ZDHC (Zero Discharge of Hazardous Chemicals) has set proactive goals to reduce DMF use in the leather industry for the coming years.

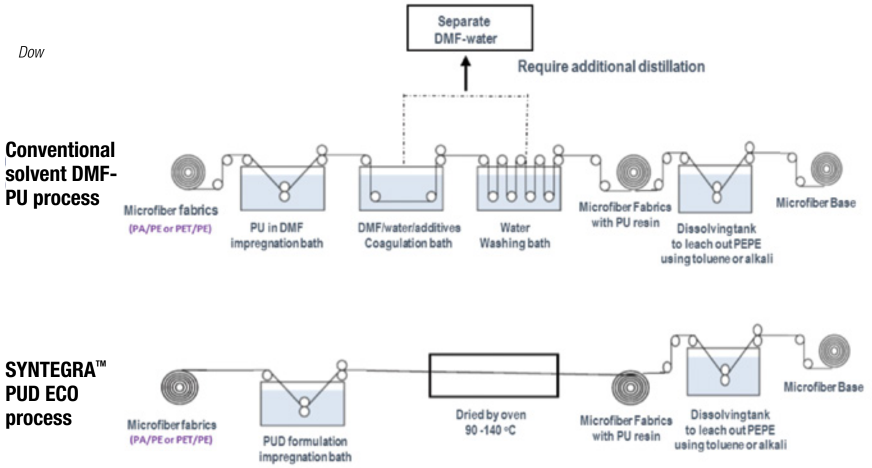

FIGURE 4. The waterborne PU dispersion process by Dow Syntegra YF4000 PUD is much simpler than the DMF-PU process. DMF-PU processes are easily retrofitted for Syntegra

Aqueous polyurethane dispersions (PUD) are regarded as one of the most promising eco-friendly solutions for DMF replacement. These realize a low viscosity and a high PU resin content system by dispersing the PU particles into water. However, the synthetic leather industry is still facing technical challenges associated with PUD microfiber fabrication. Generating "leather-like" haptics is very challenging with a good chemical resistant PUD.

In response to these technical challenges, Dow developed and commercialized Syntegra YF4000 PUD for waterborne microfiber leather fabrication, as well as its post-formulation and process for good haptics microfiber leather. These dispersions are generated using Dow's patented Bluewave technology. Synthetic leather can be designed by varying the PU polymer structure to create a cost-effective product with excellent chemical resistance. Bluewave technology, utilizing a process intensive continuous dispersing device, generates an easy-to-disperse product without using organic solvents. The final PUD product has a high solid content (>54%), which saves shipping costs (reduces the transportation of water and packaging sizes), conserves energy and reduces the overall carbon footprint for the product. Additionally, Syntegra lends itself to be easily implemented with a simple retrofit of existing solvent-based processes (Figure 4).

In a conventional DMF-PU process, there is one DMF-PU tank for resin impregnation and several DMF-water tanks for washing and an additional DMF-water distillation step needed to separate DMF and water. With Dow's waterborne process, only a single impregnation PUD tank is needed, followed with a drying oven to remove the water. Since the impregnation tank and oven are already installed in most synthetic leather factories, no new design or capital investments are required to implement Dow's new technology.

Mechanical dispersing process. Dow's proprietary Bluewave Mechanical Dispersing Process is the foundational technology needed to create the emulsified polyether-based PUD. Bluewave technology utilizes the high-internal-phase emulsion (HIPE) mechanism to generate sub-micron polyurethane particles using a surfactant that is effective without an organic solvent. With accurate metering of the PU prepolymer, surfactant and water into a novel rotor/stator in-line mixer, a well-defined particle size distribution can be generated. Within the same rotor/stator, reaction of these particles with an amine chain extender allows tailoring of the physical properties of the PUD. Finally, water is injected within this novel rotor/stator to break up and dilute the HIPE to the desired final solids level. This compact and efficient process generates the PUD continuously with particle formation, reaction and dilution steps occurring within seconds.

Scale-up and production. The Syntegra PUD family was commercially launched in microfiber applications in 2020, which has total addressable market of 300,000 metric tons (m.t.) in China.

HONOR ACHIEVEMENT
Sapphire Technologies: FreeSpin turboexpander

Sapphire Technologies, a subsidiary of Calnetix Technologies, has brought to market an axial flow-through, magnetic bearing, turboexpander generator (Figure 5) for pressure reduction energy recovery. The FreeSpin In-line Turboexpander (FIT) generator offsets carbon emissions and improves the transmission efficiency of natural gas pipelines by recovering high-pressure energy at pressure reduction stations (PRSs) and converting it into electricity. A single unit can offset up to 1,200 tons of CO_2-equivalent (CO_2e) emissions and generate 2.5GW of power per year. Market barriers of entry for this technology have been brought down by this invention for its small footprint, non-contact operation (magnetic bearings), zero maintenance, hermetic sealing and minimized capital cost.

Natural gas pipelines consume energy by compressing natural gas for high density, high efficiency transport. A significant portion of upstream compressor energy consumption is recoverable through a turboexpander generator downstream. Expansion downstream is achieved through a Joule-Thomson (JT) valve, providing an adiabatic pressure drop for the gas. To prevent pipeline freezing from the JT effect, gas pre-heating is implemented upstream from decompression to raise the gas temperature before JT expansion, an energy-consuming process. Instead of losing pressure reduction and heating energy to the environment, the turboexpander generator recovers the energy by reduction of pressure and enthalpy.

Sapphire's FIT uses a radial inflow expansion wheel to convert the gas stream energy into rotating energy and then transmits the energy to the permanent-magnet rotor. The generator then converts the rotational energy into electricity that is transmitted to the variable-speed drive (VSD). The VSD conditions the electricity to match the voltage and frequency of the local grid. The produced electricity can then be used to offset facility electrical burden or for sale to the local electric utility.

FIGURE 5. Shown here is Sapphire's FreeSpin In-line Turboexpander (FIT) system

In August 2019, outside of Bologna, Italy, a partnership between BHGE Nuovo Pignone and Calnetix in the installation of first turboexpander generator at a natural gas PRS was the basis for forming Sapphire Technologies. This installation proved successful, producing 95% of the designed power generation. The installation paired a transcritical CO_2 heat pump for gas pre-heating instead of a natural gas boiler, further increasing the system efficiency. In February 2021, the second and third FIT systems were installed at a PRS in Japan with a Japanese gas utility within 1 week of delivery, proving the ease of hardware installation.

An estimated 5,000 natural gas pipeline PRSs exist in the U.S. alone, all with the capability of FIT installation. These PRSs have the capability to produce power from several hundred watts up to several megawatts. Assuming a single FIT is installed at each of these stations, 12,500 GW of power can be recovered or 6M tons of CO_2e emissions reduced. That's enough power for 1.17M U.S. homes, according to the U.S. Energy Information Admin. (EIA) 2019 average residential home annual power consumption, or to convert 370,000 people to net-zero CO2e emissions per year according to "Our World In Data 2019" carbon footprint report.

With applicability to hydrogen and other compressed gases, the FIT will play a key role in maximizing efficiency of consumer gas energy consumption and reduction of CO_2 emissions.

Commercial implementation. In 2019, Calnetix and BHGE Nuovo Pignone commissioned a 300kW turboexpander generator designed to recover energy during pressure let down at a city gate station outside of Bologna, Italy. Calnetix provided the active magnetic bearing system, PM generator, and power electronics while BHGE provided the turboexpander housing, aerodynamic section, and skid. This was the first natural gas turboexpander project that sparked the interest in developing a product.

From 2019 to 2021, amidst the pandemic, Sapphire completed the development, building and deployment of the first FIT units to be installed at a LNG terminal station in Nagoya, Japan. Two units are currently being commissioned: a 125 kW and a 280 kW, in parallel, producing a total of 405 kW.

During the development of the first FIT systems, Sapphire Technologies was established with the intent of delivering pressure to power solutions for the pressure reduction industry. Backed by Calnetix engineering and 80+ patented technologies, Sapphire's FIT product is poised to provide a safe and reliable turboexpander product for a broad scope of pressure let down applications.

The FIT provides a way to capture the energy lost in pressure reduction. The FIT generator extracts kinetic energy from the pressure reduction and allows for the generation of electricity with no added pollution.

The FIT consists of a high-performance, high-speed permanent-magnet generator with an integrated radial in-flow expansion turbine and low-loss active magnetic bearings (AMBs). The FIT is designed to have the process gas flow through the system, which cools the generator section and eliminates the need for auxiliary cooling equipment. The power electronics for FIT combine the variable speed drive (VSD) and magnetic bearing controller (MBC) into one cabinet. The VSD allows for a consistent and clean delivery of generated power from the FIT to the grid. ■

Edited by Gerald Ondrey

If Data is the New Gold, Where to Start Digging?

In a data-overloaded environment, companies may struggle to fully reap the benefits of Industry 4.0 technologies. Understanding data utilization can help transform process datasets into decision-making assets

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IN BRIEF

The chemical process industries (CPI) have been realizing for some time that information is of strategic importance for the survival of any organization. Colloquially, data have been called a new natural resource [*1*] — every part of an organization is making decisions daily, based on data they collect, process, analyze and review. The global pandemic has further driven the awareness of digital transformation for any company, and manufacturers are no exception to this. The rise of Industry 4.0 technologies has further driven this trend, and with more and more data available, organizations are struggling to reap the benefits of these data. At the same time, the industry acknowledges that poor engineering information can have real and significant impacts, but little research has been done to quantify this. Among this mixture of promising potential and data overload, companies are struggling to define where and how to start. This article shines a bit of light on how an organization can make progress in its quest to transform its vast volume of process data into a decision-making asset.

What does data mean for CPI firms?

CPI facilities collect massive amounts of data. One way to describe the types of data being recorded is to look at the different levels of the manufacturing execution system (MES). The MES is the culmination of tools and technologies used at different levels to manage the operations of the facility. Often, the MES is also displayed as an automation pyramid. The left side of Figure 1 shows an example of an automation pyramid. Considering each of the levels illustrated in Figure 1, let us examine the different types of data being collected.

Level 1: Control and field. At this level, the input from the field is generated by sensors and equipment used in the field. Temperature, pressure, rotational speed, valve status and many other variables are generated at very frequent increments. The inputs generated at this level are provided to the second level in the pyramid.

Level 2: Operations. The second level provides low-level automation in the form of programmable logic controllers (PLCs), which ensure basic controls for individual systems and operate and respond at very high speeds.

Level 3: MES. The third level is the MES level, often executed in the form of a distributed control system (DCS) or supervisory control and data acquisition (SCADA) system. There are obvious differences between these systems, but for this article, their function is the same: to provide overarching control of the facility across multiple systems. Ref. 2 provides a good overview of the systematic differences.

Level 4. Enterprise resource planning (ERP). The ERP level provides integrated resource planning and controls the planning and resources required to generate the desired production.

Each lower level can produce data that can be used by a higher level to create a more integrated system. Research has been conducted on the importance of this integration. According to these findings, to reap the full benefits of Industry 4.0 technologies and effectively utilize digital twins, data must be aligned at all levels [*3*].

A second description of the data being generated is the supporting data used to ensure safe and compliant operations — for example, piping and instrumentation drawings (P&IDs), specifications, inspections, environmental reports, work processes for management of change (MOC), training records, and many others. Where the MES generates vast amounts of transactional and real-time data, the supporting data are more static. With the data being more static,

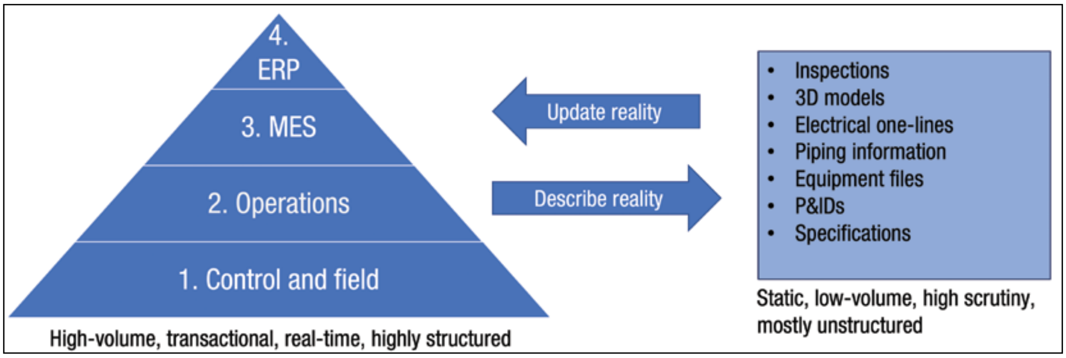

FIGURE 1. This sample automation pyramid includes the hierarchy of data sources feeding into the enterprise resource planning (ERP) system and manufacturing execution system (MES), as well as supporting datasets

the change controls put in place on these data are rigorous enough to ensure the safety and compliance of the facility.

When both types of data are presented in one overview, it becomes more evident how they interact and the importance they both play in the day-to-day operations. This is displayed in the right side of Figure 1, which shows an overview of the two important datasets. There are many interaction points, and operators, engineers, planners and project managers will use both datasets daily to operate the facility. In an ideal world, both datasets are aligned, represent reality and support the operation. The truth is very often different — companies may be struggling to keep the data updated both vertically and horizontally across both datasets. During the 2012 Offshore Technology Conference (OTC), it was stated that there is often a 12-month lag time between the real world and all information systems being correctly updated [*4*].

The impact of poor data

Previously, the types of data that are maintained and created as part of the operation for a production facility were described. With a general feel for the struggles to maintain this information, it is important to ask, why does it matter? Amongst information-management experts, there is a good sense that poor engineering information has an impact. However, when researching this topic, it is difficult to quantify the impact, as research on this topic is very limited. The usual suspects relate to safety, compliance, efficiency, improving equipment reliability and so forth. The following sections discuss some of these areas in more detail to see if there is a business case to be made before digging in further.

Trust — 50% or worse. From a limited poll during a live event, amongst process manufacturing companies, 50% of the attendees rated the trust level of their information at 50% or worse. At a minimum, this means that a field-check is required, and multiple systems would need to be verified, before committing changes to critical information [*5*].

Perceived reliability — 60%. From a study conducted in 2016 amongst nine petroleum production facilities and 133 interviews, 60% of the group reports that communication and access to information, combined with the efficiency of the tools available have a large influence — in a negative way — on the perceived reliability of the equipment [*6*].

Safety and incidents — 86%. When an incident (or near miss) happens, 86% of those surveyed at a live event for process manufacturers believed that poor, missing or not timely information was a large contributing factor to the incident [*5*].

Cost — 1.5% of annual revenue. From research performed by ARC Advisory Group (Dedham, Mass.; www.arcweb.com), it was concluded that the cost of poor asset information can be upwards of 1.5% of annual revenue for an organization. Throughout the study, these numbers have been validated against other known studies to contrast, and compare and validate the outcome of the study [*7*].

Cost — $15.8 billion per year. From a well-known report produced by the National Institute of Standards and Technologies (NIST; Gaithersburg, Md.; www.nist.gov), it was estimated that the inadequate interoperability of information is costing the capital facility industry a staggering amount yearly. Although this study was performed in 2004, reviewing some of the more recent research shown above the presented number still seems relevant [*8*].

Cost — 10% of the operating budget. From a study in 2019, it was concluded that up to 10% of an annual operating budget could be lost because of poor engineering information. Many variables are used, and depending on the specific situation these numbers will vary a lot. However, the range of potential cost is very significant for any asset that provides a solid start for a business case [*9*].

With the arguments above, it should be easy to convince leadership to invest in improving the quality of information. The reality is very different, as most of these figures represent soft or indirect savings and results that require not only a system, but also organizational changes in culture, structure and work methods to fully reap the benefits. The most recent research from Volk and Coetzer has produced a taxonomy showing an overview of the cost involved with poor engineering information for a facility [*9*]. Figures 2 and 3 show an overview of the defined taxonomy.

Executives have grown weary of large information technology (IT) projects that take a lot of time with limited hard benefits. While improving data quality sounds a bit mundane, coupling data quality with digital transformation and improving how business is conducted will have a higher chance of achieving the executive agenda.

To provide some practical guid-

ance, Frank et al., describe stages of Industry 4.0 implementation patterns, where vertical integration of information systems is one of the elementary steps to allow a company to access more advanced scenarios. In the first stage, most companies focus on vertical system integration, energy management and traceability of materials. The second stage will focus on automation and virtualization. The last stage will focus on making the production process more flexible [*10*].

From different points of view, we now see that the quality and integration of data are essential for not only improving the current operation, but also for embarking on any type of transformation project. As the journey continues, establishing the meaning of data quality is an integral part of this quest.

What is data quality?

Throughout this article, the terms data and information have both been used. Although these terms are used interchangeably from time to time, there are clear differences. Amongst academics, similar definitions emerge. The word "data" is defined as a discrete and objective description of events — for example, a temperature reading for an instrument in the facility or a listing of dates for approved changes to the facility. Information is defined as data that has been transformed to add value in a specific context by condensing, categorizing and other means to support the decision-making process [*11*]. A good example in this sense is to use the database with recorded changes (MOC) to find trends related to equipment. A valid question to ask is: are specific pieces of equipment more prone to failure compared to others? The answer could influence buying and replacement decisions.

TABLE 1. DATA QUALITY DIMENSIONS [*13*]

Dimension	No. cited	Dimension	No. cited	Dimension	No. cited
Accuracy	25	Format	4	Comparability	2
Reliability	22	Interpretability	4	Conciseness	2
Timeliness	19	Content	3	Freedom from bias	2
Relevance	16	Efficiency	3	Informativeness	2
Completeness	15	Importance	3	Level of detail	2
Currency	9	Sufficiency	3	Quantitativeness	2
Consistency	8	Usability	3	Scope	2
Flexibility	5	Usefulness	3	Understandability	2
Precision	5	Clarity	2		

Another popular buzzword in this discussion is "big" data. The obvious point to look for big data applications is along the lines of the automation pyramid with technologies such as predictive maintenance. In the context of big data, there is often a reference to the "five Vs," as follows:

1. Volume — Describes large amounts of data either stored or in transit
2. Variety — Speaks to both structured and unstructured data and a wide variety of data sources
3. Velocity — Describes the speed at which the data volume increases, often at a very high level
4. Veracity — Relates to the accuracy and quality aspect of the data
5. Value — The value created by the data for the organization [*12*]

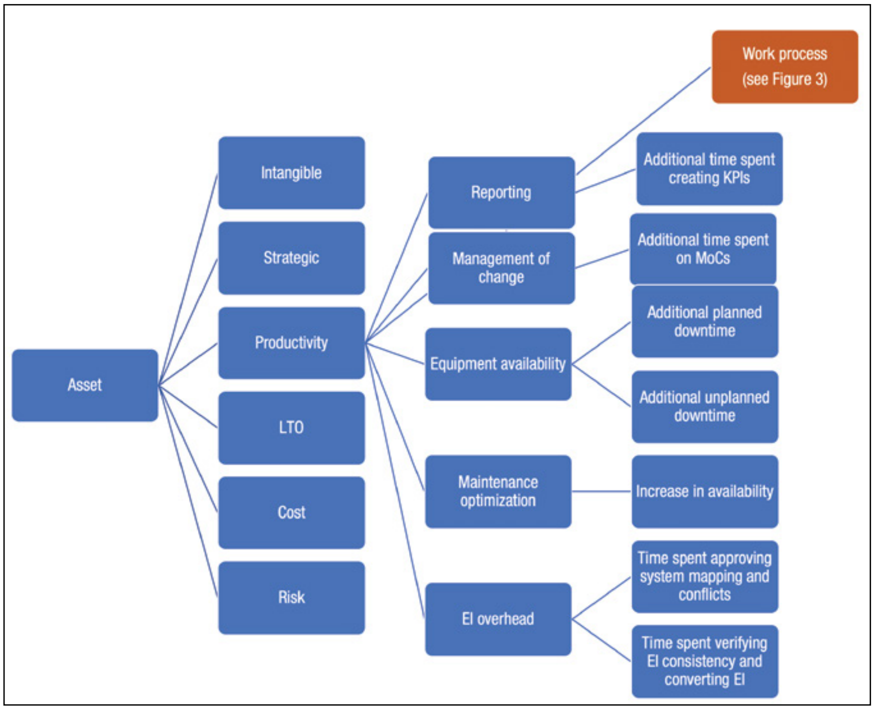

FIGURE 2. This taxonomy gives an overview of the potential costs associated with poor engineering information [9]

Big data is not a state of being that one can achieve, but rather more of a framework for tools and methods used with varying data sources to deliver value from these complex and large data sources.

While combining different data sources at large volumes with varying complexity across structured and unstructured data is at the core of a big data project, it is easy to see how important it is to have data aligned both horizontally and vertically. For many facilities, through the years, data have been managed differently, with the result that a simple equipment tag is often labeled differently in all the different systems. Searching for information on a specific pump becomes that much more difficult, and users must navigate between asset management, drawings and SCADA systems to find the information they are looking for. Aside from system requirements that force inconsistencies,

information is often transferred in a manual way, which compounds the underlying issue.

Although there is a logical inclination to look at the automation pyramid for big-data applications, using asset-management systems and document-management solutions can provide a trove of useful information. Utilizing process analytics, it is now possible to optimize business processes, while learning from real-world application usage. This capability can help to debottleneck common work processes.

Finally, data are classified into two major types — structured and unstructured. Structured data are stored in databases, such as historians, ERP systems, document-management systems and so on. Structured data are often used for reporting and analytics. On the other hand, there is unstructured data, consisting of documents, drawings, specifications, emails and so on. Due to the unstructured nature, it is much more difficult to gain knowledge from unstructured data. It is often anecdotally referenced that any given enterprise has about 80% unstructured data and about 20% structured information.

Armed with a better understanding of the kinds of data available, let us review some of the quality aspects that are essential to any dataset. Whether they are used for small-scale integration or a big-data initiative, these aspects remain valid.

Data quality can be, in simple terms, referred to as fitness for use. Wand and Wang [*13*] have used commonly cited dimensions from literature to describe data quality. Table 1 lists the most cited dimensions that describe data quality. Not all of these dimensions are applicable for all data sources, but this table can serve as a good means of assessing data quality. Each of these aspects can be different for a given data source, and it is up to the company to define what these levels of quality mean for the given dimension. As a practical example, let us assume the information presented on the title block for a draw-

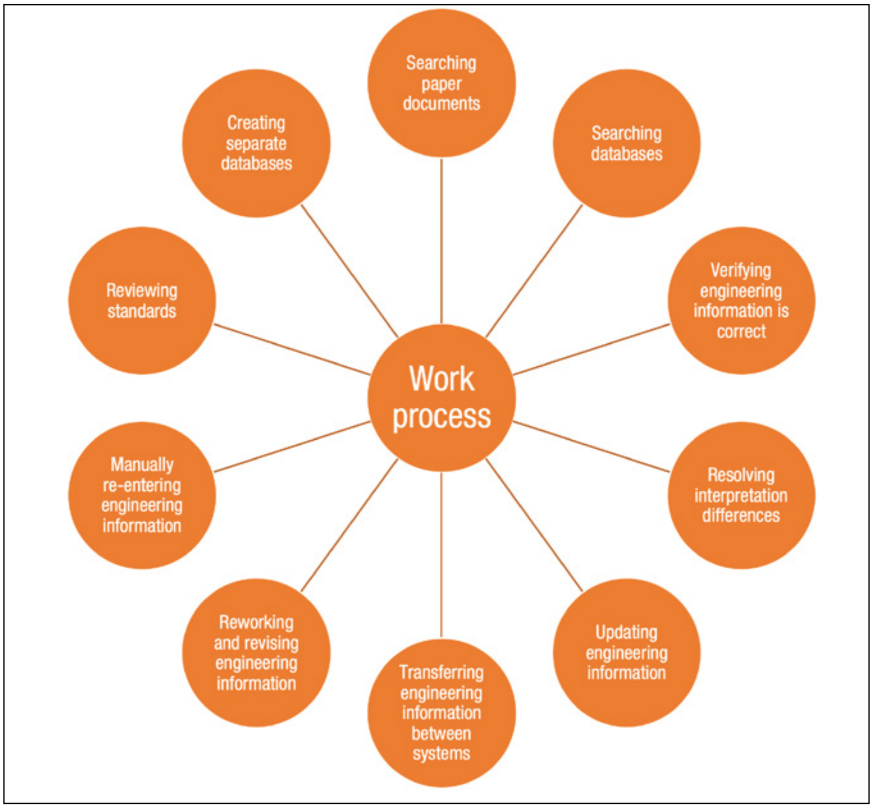

FIGURE 3. If an organization is dealing with poor engineering information, there are many work-process activities that may require significant additional time

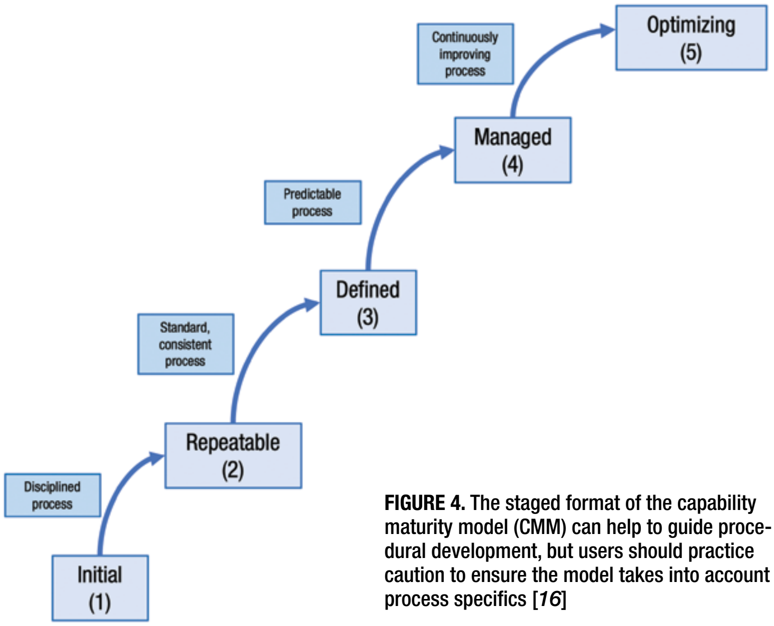

FIGURE 4. The staged format of the capability maturity model (CMM) can help to guide procedural development, but users should practice caution to ensure the model takes into account process specifics [*16*]

ing. When referring to the completeness dimension, a company could define that a complete title block should contain the drawing number, revision, revision date, approver, reviewer, editor and other elements of information. For the format dimension, the company could define that for each P&ID, there is at least a PDF version and an associated native (for instance, a CAD drawing) version of the document. Several industry standards are available that can serve as a starting point in this regard, such as ISO 15926, CFIHOS and PIP standards.

What are maturity assessments?

At present, it is close to impossible to look at any business process that is not dependent on information and communications technology (ICT) in some shape or form. To what extent this process is optimized and aligned with the strategic goals is a different question and relies on a continuous improvement process and assessment of the current position against internal and external goals, laws and requirements [*14*].

As business leaders seek to make improvements, they need management instruments and methods to drive their agenda. This is where maturity models come into play — using the model for evaluation of the current state, as well as providing direction for improvements [*15*]. For a given business area (such as information quality), a maturity model allows an organization to measure itself against a given set of criteria.

Depending on the design of the model, this measurement takes the form of level descriptions, where each level provides an established list of criteria to achieve the level. Alternatively, measurements can be taken based on a Likert scale (bipolar) approach where a detailed question will guide the respondent in answering, using a pre-defined scale. In both cases, the lower score represents an area that is less developed, where the higher scores represent well developed or optimized areas. The scoring then presents a potential roadmap for a given domain as it progresses to higher levels on the scale.

ICT maturity models found their origins from the need to better manage software processes, during the late 1980s and 1990s when many ICT projects were over budget and excessively late, while often not delivering what was promised. The Software Engineering Institute, with support from Mitre Corp., developed the first process maturity model, which later evolved into the capability maturity model or CMM [*16*]. Figure 4 shows the different maturity stages often used in maturity models.

At present, maturity models are available for an almost unlimited number of topics. Performing a quick search on the internet will show maturity models for digital transformation, Industry 4.0, project management and almost any other topic one can think of. Although these models are widely credited for their usefulness, there is also a cautionary tale. The quality of the model and associated assessment is highly dependent on the specific application. To use a generic document-management maturity model about engineering information will leave out important elements. There are also many maturity models created that barely pass the academic stage. In selecting a model and assessment, selecting a widely used model will ensure higher accuracy and relevance to your organization.

Avoiding problems

While maturity assessments are a great management tool, it is important to define the proper scope and define the expectations for what the maturity assessment project will deliver. One of the key elements in digital transformation is to experiment and fail fast. While a maturity assessment will validate and provide direction, it is key to identify practical goals that can be resolved within a foreseeable timeframe and build success. Organizations currently use the term "business agility," meaning that there is a desire to address problems quickly as the business evolves in an ever-changing landscape. The purpose of an assessment is that it will provide a roadmap whereby identified improvements can be executed, contributing to the goals of the company.

With the result of an assessment available, it is now time to translate the measurement into executable goals. One methodology is to discuss the different areas of the assessment and rate these areas on a priority scale, taking into account the company goals, budgets and available resources. Based on the selected areas (for instance, deliverables management) the organization then uses the following goal

methodology (SMART) to define the improvement project [*17*]:

- Specific — What the project will accomplish with a very specific goal
- Measurable — How the success of the goal can be measured.
- Assignable — Who in the organization (internally or externally) will be responsible for this goal
- Realistic — Why this goal is attainable
- Time-related (or time-bound) — The timeframe for when the goal is to be completed

The combination of the SMART Goals, combined with the outcome of the assessment, provides management teams with the instruments to measure the current status, but also any future progression. The defined goals provide a method to execute specific projects that will raise the level of maturity on the topic of data quality. ■

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Health, Safety and Environmental Considerations for Process Synthesis

Following this approach to assessing health, safety and environmental risks can steer engineers to consider more inherently safe process options earlier in process synthesis

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IN BRIEF

During process synthesis in the chemical process industries (CPI), engineers make decisions that determine the inherent health, safety and environmental (HSE) risk level of a process. This article proposes a simple approach for identifying and assessing the major HSE hazards during synthesis.

Understanding the risk level during synthesis enables the engineer to consider inherently safer designs (ISD) while developing the flow sheet. If risk levels are not considered during synthesis, higher risk processes will result, because decisions are hard to change once the flow sheet has been finalized. Most of the resistance to process design changes comes from trying to avoid the need to repeat expensive research and development work, as well as avoiding schedule delays.

To understand the value of ISD, consider the Bhopal, India incident where, in 1984, an accidental release of the chemical methyl isocyanate (MIC) occurred at a facility for manufacturing the insecticide Sevin. MIC, an intermediate in the production process for Sevin, is a highly toxic chemical. A National Research Council (Washington, D.C.; www.nationalacademies.org) study stated that more than 40 tons of MIC were released, killing close to 3,800 people and seriously injuring between 100,000 and 200,000 [*1*]. Had there been an inherently safer process at the Bhopal plant, the accident might have been prevented, or its severity greatly reduced.

What is process synthesis?

Process synthesis is the creation of a process for manufacturing a product that meets customer-based quality specifications, has an appropriate level of HSE risk, and meets business and economic requirements [*2*]. When complete, process synthesis will have defined the following:

- A block flow diagram of the process, showing all major process steps and flow streams
- Process operating conditions
- Material specifications for raw materials, catalysts, solvents, processing aids, packaging materials and so on
- Material and energy balances
- Required materials of construction
- Process design data, such as reaction kinetics and physical properties
- Scale-up criteria
- Major HSE hazards

How to think about HSE

HSE is a broad topic dealing with the safety of plant employees, of the physical plant, of the community and of the environment. Each of these constituencies is affected in its own way by a production process.

- Plant employees may be affected by chemical exposure, fire, explosion, noise and injuries
- The physical plant may be affected by fire, explosion and overpressure situations
- The community may be affected by accidental releases of substances, fires, explosions, noise, pollution, landfills and the disposal of hazardous chemicals
- The surrounding environment may be affected by planned emissions and discharges, toxic wastes, accidental releases and fugitive emissions

In the previous definition of process synthesis, the phrase "appropriate level of HSE risk" requires further explanation. Generally, risk is thought of as the following:

Risk = (Severity of Incident) × (Likelihood of Occurrance)

or

Risk = (Human and/or Economic Loss Potential) × (Probability of an Incident)

The definition of acceptable risk varies from company to company. Each organization must define what is appropriate for it, which is a difficult task at best. If the question were simply financial, such as weighing the cost of risk reduction against the monetary loss of an incident, it would be fairly straightforward to answer. The difficulty arises when one has to consider the loss of life or personal injury. What is a life or severe injury worth? What is an acceptable fatality rate? These are hard questions to answer.

In a recent article about COVID-19, Alex Berezow discussed the value of life [*3*]. Although he wrote the article from a geopolitical perspective, his remarks apply equally to HSE. He states there are three ways to view the value of life: morally/philosophically, economically and a blend of the two.

"Many people say that one cannot put a price tag on human life. This is true from a moral or philosophical perspective. … In the eyes of an economist, however, we are neither equal nor invaluable.

"How does one begin to put a price tag on a human life? A simple thought experiment demonstrates how easy it is. Pretend that you're the mayor of a small town. There's a dangerous intersection that results in one car crash fatality every year. A company approaches you with a solution: By redesigning and rebuilding the intersection, it can guarantee no more car crashes. The only problem is that the infrastructure project costs $100 million. Considering that your small town's budget is far less than that, the city couldn't afford it without a massive tax increase. You propose that tax increase to your citizens, who reject it overwhelmingly. The citizens have spoken: The lives of those who will be killed in accidents at the intersection are not worth $100 million.

"… For what it's worth, various U.S. government agencies value a life between $9 million and $10 million.

"The key is to remember that we are talking about economic value rather than moral value. There is always space for a moral consideration in geopolitics, but it too must be considered along with other factors."

When thinking about risk, engineers should also consider the information shown in Tables 1 and 2, as well as their own company's data and practice.

TABLE 1*. TYPES OF CHEMICAL PLANT INCIDENTS

Type of incident	Probability	Fatality potential	Economic loss potential
Fire	High	Low	Intermediate
Explosion	Intermediate	Intermediate	High
Toxic release	Low	High	Low

*Adapted from Table 1-6 in Crowl and Louvar, Chemical Process Safety, 3rd ed. [*9*]

TABLE 2. COMPARATIVE FATALITY DATA

Fatality cause	Deaths per 100,000 people
Smokers who smoke ≥15/d (2005–2009)[a]	1,000
Car travel (2019) [b]	12
U.S. Manufacturing (2018) [c]	2.2
Chemical Manufacturing (2018) [c]	1.2
Being struck by lightning (2006-2019) [d]	0.07

Source data:
[a] 2014 Surgeon General's Report, Table 12.4, p. 660
[b] National Safety Council
[c] Bureau of Labor Statistics
[d] National Weather Service

Methodology

The methodology presented here will help to find and assess HSE hazards during process synthesis. For hazards that could result in serious or catastrophic incidents, the engineer should consider changing the basic process to make it inherently safer. Because synthesis is the time when the process is being created, it is the ideal time to explore options for hazard elimination or mitigation. During synthesis, one need not work on routine safety issues, such as pressure relief. Later on, detailed studies, such as HAZOP (hazard and operability analyses), will identify these issues.

The steps in the methodology are the following:

- Identify the hazards
- Estimate the potential for loss
- Estimate the probability of having an incident
- Identify the major risks
- Consider inherently safer designs

Step 1: Identify process hazards. Begin by looking for toxic release, explosion and fire hazards, as follows:

- *Hazardous materials*. For each flow stream in the process, list the composition, materials and amounts of each stream. This should include intermediates and impurities. Consider feed streams, products, byproducts, recycle streams, purge, catalysts and solvents, as well as planned discharges to sewers, the atmosphere, landfills, recyclers and waste disposal firms. For each substance, determine whether it is hazardous; and if so, the degree of hazard it presents. One needs to consider health, flammability, instability and special hazards. An example of a material having a special hazard is MIC, which reacts violently with water. This is believed to be the initiating cause of the Bhopal incident mentioned previously. Usually, the National Fire Protection Association (NFPA; Quincy, Mass.; www.nfpa.org) or the U.S. Hazardous Materials Identification System (HMIS) ratings are sufficient sources of information to determine the hazard level of a chemical. Both systems have five rating levels. Table 3 explains the NFPA levels. HMIS is similar.
- *Process-related hazards.* Some operating features and equipment in a process may be hazardous. The most common are runaway reactions, high temperatures, high pressures (or vacuum) and large inventories of hazardous materials.
    - *Runaway reactions.* Runaway reactions are a fairly common problem. High heats of reaction and large reactor volumes increase the probability of an incident. If a reaction is exothermic, assess the chances that it could get out of control. This usually occurs when there is a problem, such as a cooling system or power failure. An assess-

ment of the system requires knowing the reactor volume, the heat capacity of the reaction mix, the heat of reaction and the reaction rate. If the last three pieces of information are unknown, the data can be obtained via reaction calorimetry experiments.

- *High-pressure or high-temperature operations.* These are innately more hazardous than lower-pressure and lower-temperature operations. High pressures increase the odds of having an equipment or piping leak. When a process stream is within or near its flammability range, or near or above its flash or auto-ignition temperature, leaks may result in a fire or explosion. The same is true of leaks of flammable heat-transfer fluids. A special category of high-temperature operations is furnaces. By their nature, furnaces are risky. If a furnace is used to heat a process or a heat transfer fluid that is flammable, tube leaks could result in a fire or explosion. Also, high-temperature operation weakens the strength of the tube materials increasing the probability of leaks.
- *Vacuum operation*. While vacuum operations are usually safer than high-pressure operations, air leaks into a process stream that will oxidize or that is combustible could cause an incident.
- *Hazardous material inventories*. The issue here is the possibility of an accidental release. The larger the inventory of hazardous materials, the higher the chance of having a catastrophic incident. Inventory was a major contributor to the large number of deaths in Bhopal. Inventories include both in-storage and in-process material. When considering in-process inventory, keep in mind that batch reactors generally have higher volumes than continuous reactors, standard distillation columns arranged in sequence contain more liquid than a divided-wall column does, and plate towers hold more liquid than packed towers do.

TABLE 4. HARDWARE RELATED TO INCIDENTS FOR THE REFINERY AND PETROCHEMICAL INDUSTRIES, 1974–2019

Hardware	% of Incidents
Piping, including valves	33
Towers	14
Reactors	12
Storage tanks	7
Unknown	4
Instruments	3
Heat exchangers	3
Pumps	3
Compressors	2
Other	19

Source data: Marsh, The 100 Largest Losses in the Hydrocarbon Industry 1974–2019, www.marsh.com/us/insights/research/100-largest-losses-in-the-hydrocarbon-industry.html

Step 2: Estimate loss potential. Once the hazards in the process have been identified, engineers should assess the potential for loss for each hazard. Because there are few design details at this point, these assessments will be "order-of-magnitude" quality. As such, they are only useful during synthesis. They do not take the place of the exacting safety studies done later during detailed design.

Referring back to Table 1, note that toxic releases and explosions have the greatest potential for fatalities and economic loss. To estimate each hazard's potential for loss, place each into one of the following broad loss categories:

- Catastrophic — Those resulting in deaths or permanent disabilities, major community damage, or major plant damage
- Major — Those resulting in hospitalizations, significant community damage, or significant plant damage
- Moderate — Those resulting in injuries needing medical treatment, minor community damage, or moderate plant damage
- Minor — Those resulting in minor injuries, no community damage, or minor plant damage

When assessing the loss potential of materials, one can use NFPA or HMIS ratings to define the severity of health, flammability or instability hazards. If these are not available, use the Materials Safety Data Sheets (MSDS) for each substance or PubChem's Compound Summary database [*4*]. If a material has an NFPA or HMIS rating of 4, assign its potential for loss as Catastrophic. A 3-rating should be assigned the loss category of Major, and so on. To illustrate, MIC, the toxic intermediate in the Bhopal Sevin process, has an NFPA health rating of 4. Thus, its loss potential would be Catastrophic. Its release was clearly that.

TABLE 3. THE NFPA RATING SYSTEM

Adapted from Figure 3-8 in Crowl and Louvar, *Chemical Process Safety, 4th* Ed. [*5*]

	4	3	2	1	0
Health rating	Can be lethal	Can cause permanent or serious injury	Can cause temporary incapacitation or residual injury	Can cause significant irritation	Not hazardous
Flammability rating	Rapidly vaporizes and burns at room temperature	Ignites easily at ambient temperatures	Ignites when moderately heated	Must be preheated to ignite	Will not burn
Instability rating	May detonate	Shock and heat may detonate	Violent chemical change at elevated temperatures	Unstable if heated	Stable

Special hazards
OX: Oxidizer
W: Violent reaction with water
SA: Simple asphyxiant

For process hazards, the guidelines are not as clear cut. The Marsh 100 Largest Losses Report provides perspective. Marsh, an insurance-brokerage and risk-management firm, regularly publishes global incident data. As this report only reports the largest global losses, it represents only the tip of the loss iceberg. Property losses follow a similar pattern to deaths and injuries. Crowl and Louvar suggest that for every 1 to 2 fatalities resulting from an incident, there are 10 to 20 serious injuries, 100 to 200 minor injuries, and 1,000 to 2,000 near misses [5].

TABLE 5. RISK RATING MATRIX FOR PROCESS SYNTHESIS

Loss potential \ Event probability	Very likely, Every 0–10 years	Probable, Every 10–30 years	Possible, Every 30–100 years	Unlikely, >100 years
Catastrophic: • Deaths or permanent disabilities • Major community damage • Major plant damage				
Major: • Hospitalizations • Significant community damage • Significant plant damage				
Moderate: • Injuries needing medical treatment • Minor community damage • Moderate plant damage				
Minor: • Minor injuries • No community damage • Minor plant damage				

The March 2020 Marsh report covers the 46-year period from 1974 to 2019. It describes the 100 largest global hydrocarbon industry losses. Fifty eight of those came from the petrochemical and petroleum refinery segments. These resulted in losses totaling $23 billion, as well as the following:

- Losses averaged $500 million/yr
- The average cost of an incident was $397 million
- Three incidents (5%) resulted in toxic releases
- 39 (67%) began with an explosion
- 19 (33%) began with a fire

Table 4 summarizes the hardware and equipment associated with the 58 incidents from the petrochemical and refining sectors.

Step 3: Estimate the probability of an incident. As was the case

with loss potential, it is impossible to make detailed estimates, so order-of-magnitude quality has to suffice at this point. Assign each hazard to one of four levels of probability, which are the following:

- Very Likely — occurring every 0–10 years
- Probable — occurring every 10–30 years
- Possible— occurring every 30–100 years
- Unlikely — occurring once every 100 years or more

As previously mentioned, larger losses occur less often; smaller losses are much more frequent. The synthesis engineer, when assigning one of the four probability levels to the hazards, should consult with experienced process safety experts and refer to company incident history.

Step 4: Identifying major risks. Risk is the combination of loss potential and probability. When assessing risk during synthesis, use the Risk Rating Matrix (Table 5). First, enter the loss potential and probability estimates into the figure. If a material or other hazard falls into one of the red cells, it is important to work to eliminate, or greatly reduce, risk by applying ISD. Hazards falling into the yellow cells are borderline candidates for ISD.

Step 5: Consider inherently safer designs. The activities of hazard and risk identification lead directly to the question of what to do about high-risk hazards. In general, there are two options: use ISD principles or add safeguards to the process. Of the two, ISD is generally preferred because it focuses on the elimination or lessening of the hazard. It also delivers simpler, more straightforward designs. Kletz and Amyotte state, "Traditional plant designs try to reduce the risk by adding protective equipment and following safe methods of working. Inherently safer and friendlier plants remove or reduce the hazards" [*6*]. Protective equipment and safe practices will eventually result in an incident as equipment fails or people make mistakes.

Three pillars of ISD apply to process synthesis: substitution, minimization and attenuation. These pillars involve elimination of hazardous materials, use of much smaller quantities of them, and use of less hazardous operating conditions.

Substitution. This focuses on substituting non-hazardous or less-hazardous materials for hazardous ones. Consider the following:

- Using a reaction chain that doesn't use hazardous materials (raw materials or catalysts) or that doesn't produce hazardous intermediates or byproducts
- Pretreating the feed to eliminate impurities that react to form hazardous materials
- Using materials with higher flashpoints, boiling points and other properties that are well away from the operating conditions of the process
- Using different solvents, heat-transfer fluids or refrigerants to eliminate those that may be toxic or flammable

Minimization (intensification). The focus here is to minimize the amount of hazardous material in the system. Consider the following:

- Continuous or semi-batch systems, which usually hold smaller volumes of material compared to batch systems
- Changing reactor conditions — catalyst, temperature, pressure — to increase the reaction rate and make the reactor smaller
- Using a column sequence that minimizes the amount of hazardous material held in the process
- Using equipment having less holdup. A few examples are: divided-wall distillation columns, packed versus tray columns, thermosiphon versus kettle reboilers, plate versus shell-and-tube exchangers, and tubular versus pot reactors

Attenuation (moderation). Attenuation stresses the use of less hazardous operating conditions when handling hazardous materials and situations. Consider the following:

- Processing flammable materials well below their flash points and boiling points
- Handling explosive dusts as slurries
- Reducing the risks of a runaway reaction
- Using a smaller reactor (for example, a continuous versus batch reactor)
- Controlling the reaction rate via the order of chemical addition or by catalyst choices
- Adding inert materials to flammable mixtures
- Reducing process operating temperatures to eliminate the need for furnaces

Example

The following discussion about Bhopal and MIC illustrates substitution and minimization.

With an NFPA health rating of 4, MIC is very hazardous. As such, it would be placed in one of the red cells of the Risk Rating Matrix (Table 5). Thus, the reaction that produces it would be a prime candidate for ISD. As understood today, substitution is possible, because there are two accepted routes for making carbaryl (Sevin) [*7*]:

- The MIC route (used in Bhopal):

1. Methylamine + Phosgene ➔ MIC + 2 HCl
2. MIC + α-Naphthol ➔ Carbaryl

- The non-MIC route. This route uses the same feedstocks, but reacts them in a different order.

1. α-Naphthol + Phosgene ➔ Naphthol chloroformate + HCl
2. Naphthol chloroformate + Methylamine ➔ Carbaryl + HCl

Had the non-MIC route been used at the Bhopal, India facility, there would have been no incident — no deaths and no injuries. Even safer routes might be possible if something less hazardous could be substituted for phosgene, which has an NFPA Health rating of 4 [*8*].

There are also minimization options. Had the amount of MIC stored been small, far fewer people would have died or been injured. Recall, over 40 tons of MIC were released. It was this large release that caused the high number of deaths and injuries. Crowl and Louvar refer to a redesigned process that could reduce the MIC inventory to less than 20 lb [*9*]. In addition, the National Research Council in their report "The Use and Storage of Methyl Isocyanate (MIC) at Bayer CropScience,"

refers to a process that produces gaseous MIC, which is consumed immediately [*10*].

Unaddressed risks/hazards

If significant hazards/risks exist that are not dealt with, they should be flagged so they will not be forgotten in the future. This helps ensure someone will design safeguards into the process to manage those risks and mitigate outcomes. For example, one of the senior chemical engineering design projects at the University of Cincinnati involved designing a greener process for making dimethyl carbonate [*11*]. The process uses a catalyst (methyl iodide) with an NFPA health rating of 3. The Safety and Hazard Section of PubChem's Compound Summary for methyl iodide states that storing amounts greater than or equal to 7,500 lb "presents a potential for a catastrophic event …" [*12*]. This is the type of item one would flag, because storage systems are not dealt with during process synthesis.

Concluding remarks

The decisions made during synthesis set the HSE features of a process. Thus, it is imperative HSE be integrated into the process design. Especially with chemical processes, it is the only way HSE risk can be adequately dealt with. The approach in this article enables the synthesis engineer to identify and manage the major HSE hazards and risks in a process. ■

Edited by Scott Jenkins

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The Importance of Steam Quality for Steam-System Process Operation

Often, operational problems in steam systems are misattributed because the system's steam quality is not closely monitored. A clear understanding of steam quality can help to better address these issues

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Steam quality describes the proportion of saturated steam (vapor) in a saturated condensate (liquid)/steam (vapor) mixture. A steam quality of 0 indicates 100% liquid (condensate), while a steam quality of 100 indicates 100% steam. One pound of steam with 95% steam and 5% liquid entrainment has a steam quality of 0.95, for example.

The parameters needed to obtain a steam-quality measurement are temperature, pressure and entrained liquid content. A high percentage (88% or more) of industrial steam systems use saturated steam for process applications. Saturated steam (meaning steam that is saturated with energy) is completely gaseous and contains no liquid.

The boiler operation uses chemical energy from a fuel source to deliver energy to the boiler water. Inside the boiler, liquid gains energy from the combustion process and changes state into saturated steam. As illustrated in Figure 1, water enters the boiler at point A, and the water gains sensible energy (h_f) up to point B. The change of state is referenced as point B in Figure 1. As the saturated steam acquires more energy from the boiler combustion process, the steam achieves a high quality (moving left to right), as represented by points B to C. The increase in energy gained by the steam from points C to D goes toward the superheat of the vapor.

A directly proportional relationship exists between temperature and pressure in saturated steam. This means that as the temperature increases, so does the pressure. Illustrated by the lines of constant pressure in Figure 1, more sensible energy (h_f) is needed for water to transition from point A to point B and become a vapor. When steam enters the process, the energy level goes from right to left as the process absorbs the energy from the steam.

Steam is a vital and critical part in producing final products in chemical processing facilities. Therefore, steam quality should be one of the main measurable points in creating a product in today's manufacturing facilities. Manufacturers of heat transfer components, such as heat exchangers and tracing elements, base their performance calculations on 100% steam quality, unless the manufacturer is informed by the end user that the steam quality is lower than 100%.

Unfortunately, steam quality is typically not monitored closely and is often assumed to be 100% when that may not be reality. Therefore, issues that arise from poor steam quality are frequently blamed on some other item in the system. Based on field documentation, a high percentage of steam systems are operating below acceptable steam quality levels.

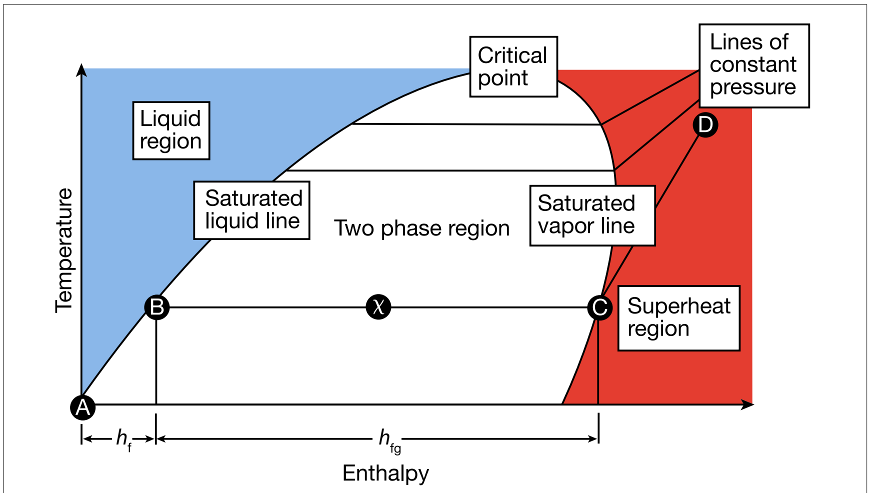

FIGURE 1. The relationship between enthalpy and temperature in a boiler is crucial for understanding steam quality

The impact of steam quality

Low steam quality affects steam system operations in many ways. Four examples are described below.

Reduced heat transfer efficiency. The major problem with low steam quality is the effect on heat transfer equipment and the process. In some cases, low steam quality can reduce heat transfer efficiency by more than 65%. The liquid entrained in the steam has sensible energy (16% estimated; this varies with pressure), which has a significantly lower amount of energy than the steam vapor's latent energy (94%). Therefore, less usable energy is being delivered to the process steam equipment.

Also, the additional liquid (low steam quality) collects on the wet surface of the heat exchanger, causing an additional buildup of liquid, which reduces the ability of the steam's latent energy to be transferred to the product.

Premature valve failure. Liquid passing through steam control valves will erode the internals of the

FIGURE 2. Visual inspection can be used to show that steam is of acceptable quality. The steam should be nearly invisible

FIGURE 3. This highly visible steam is not of acceptable quality

FIGURE 4. Visual inspection shows that there is clearly liquid being discharged with the steam, indicating poor quality

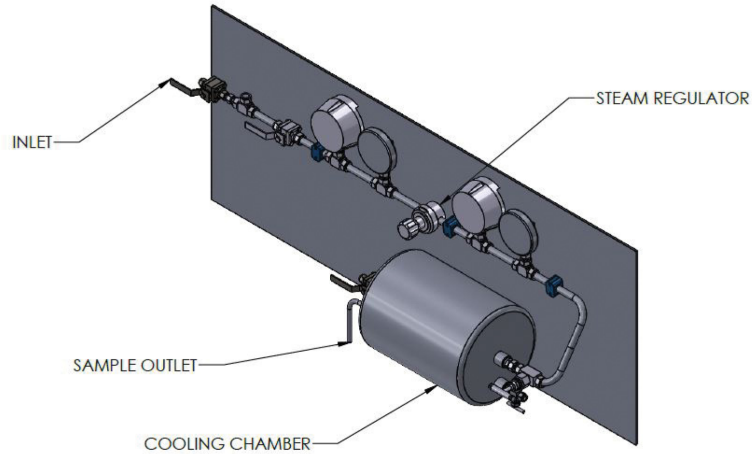

FIGURE 5. Steam calorimeters are used to determine the moisture content of steam

valves, causing premature failure.

Internal turbine component failures. Liquid introduced with the steam in a saturated turbine operation will reduce the life expectancy of the internal components.

Waterhammer. Steam systems are usually not designed to accommodate the additional liquid in steam. Additional liquid creates the chance for waterhammer to occur. Waterhammer poses a safety risk and may cause premature failure in the steam system.

Visually measure steam quality

A true measurement of steam quality can be obtained from the use of a throttling calorimeter and Ganapathy's steam plant calculations [*1*]. Unfortunately, most industrial plants do not have the luxury or capability of doing such rigorous steam quality testing.

Another way to measure steam quality is by relying on the basics of steam. Saturated steam is a dry invisible gas and only becomes visible with the presence of entrained air or liquid. Therefore, opening a steam valve and allowing steam to be released into the atmosphere provides a visual manner of estimating the steam quality in the system. To learn more about steam valves, read Proper Sizing and Installation for Steam System Safety Valves, *Chem. Eng.*, July 2017, pp. 48–51.

This is a steam quality test that all plants can and should conduct on a routine basis. Figure 2 indicates an acceptable steam quality. The discharge from the valve through the tube is almost invisible. Figure 3 shows the discharge from the valve off the steam line to be very visible, with liquid being discharged with the steam vapor. This steam quality is not acceptable for the process. Figure 4 shows the discharge from the valve off the steam line to be very visible, with liquid being discharged with the steam vapor. The steam quality is also not acceptable for the process.

Steam calorimeters

The measuring device used to determine the moisture content of steam is called a steam calorimeter (Figure 5). However, the device really does not measure the heat in the steam. The first known name used was the "barrel calorimeter," but the liability of error was so great that the device was totally abandoned. Modern calorimeters are generally either the throttling variety or a separator measuring device. All steam-quality measuring devices use the same principle, which is described in the pressure-reducing section of this article.

Throttling calorimeter. Figure 6 shows the typical form of a throttling steam calorimeter. Steam is flowing from a vertical main steam line through the sampling nipple. The steam then flows around the first measuring thermometer cup, then passes through a 1/8-in. orifice in a disk between two flanges, around the second measuring thermometer cup, and then is released to the atmosphere. The instrument and all pipes and fittings leading to it should be thoroughly insulated to diminish the energy loss that can affect the measurement. The small orifice can have issues with corrosive material flowing through the measuring device. Therefore, proper steam filtration needs to be part of the measuring system. The discharge steam piping needs to be short to prevent any backpressure below the disk area and causing an error in the measurement.

Compact throttling calorimeter.

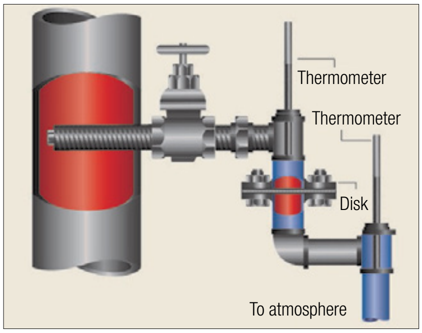

FIGURE 6. A throttling calorimeter's discharge piping should be short to minimize backpressure

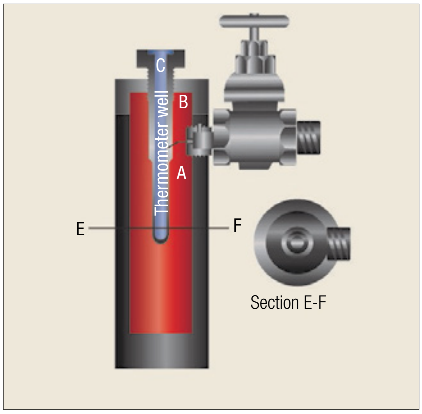

FIGURE 7. A compact throttling calorimeter employs two concentric cylinders

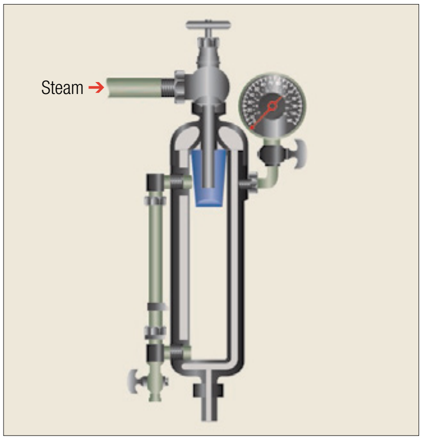

FIGURE 8. A separating calorimeter mechanically separates entrained water from steam for measurement purposes

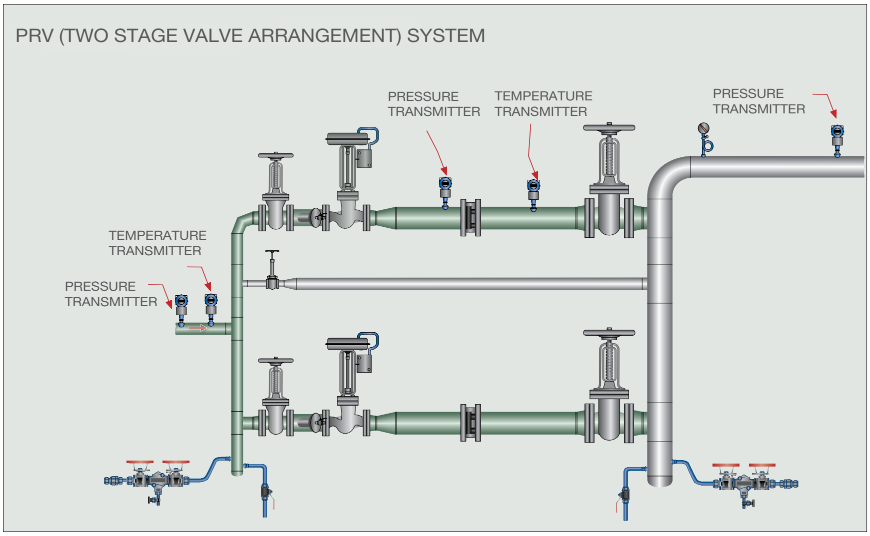

FIGURE 9. In a steam pressure-reducing valve (PRV) station, temperature and pressure readings can be either from indicators or transmitters

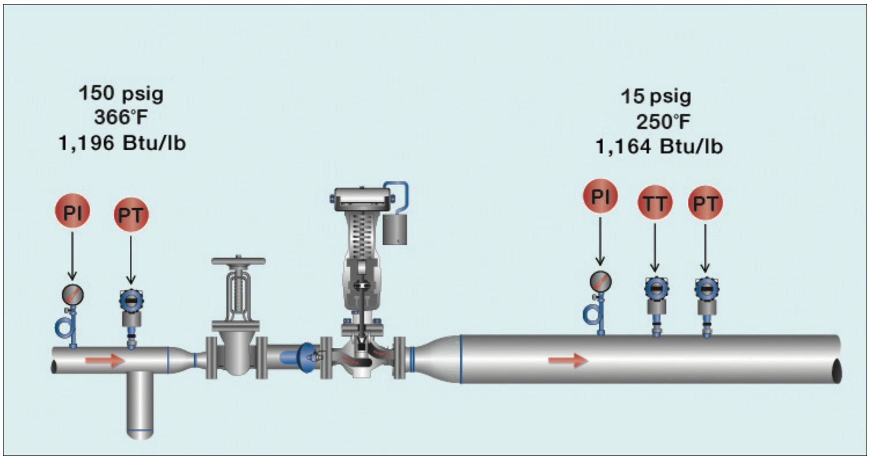

FIGURE 10. Reducing pressure across the station results in a reduction in specific energy, as well as a superheating effect

There are many forms of throttling calorimeters, each of which work upon the same principle. A compact throttling calorimeter (Figure 7) consists of two concentric metal cylinders connected to a cap containing a thermometer well. The steam pressure is measured by a gage placed in the steam supply pipe or other convenient location. Steam passes through the orifice (point A in Figure 7) and expands to atmospheric pressure. The steam temperature at this pressure is being measured by a thermometer placed in the cup (point C). To prevent radiation losses, the annular space between the two cylinders is used as an insulating jacket, since steam is being supplied to this space through the hole (point B).

Separating calorimeter. A separating calorimeter (Figure 8) mechanically separates the entrained water from the steam and collects it in a reservoir, where its amount is either indicated by a gage glass or where it is drained off and weighed. The steam passes out of the calorimeter through an orifice of known size so that its total amount can be calculated, or it can be weighed. A gage is ordinarily provided with this type of calorimeter, which shows the pressure in its inner chamber and the flow of steam for a given period, this latter scale being graduated by trial. The instrument, like a throttling calorimeter, should be well insulated to prevent losses from radiation.

Pressure-reducing stations

A steam-pressure-reducing valve (PRV) station (Figure 9) will work the same way as a throttling calorimeter. In a typical installation of a steam-pressure-reducing station, upstream and downstream pressure measurements, with the addition of a temperature measurement downstream, will provide the continuous online "steam calorimeter" functionality.

When steam passes through an orifice (within the valve internals) from a high steam pressure to a lower steam pressure, as is the case with the throttling calorimeter, no external work has to be done in overcoming a resistance. Hence, if there is no loss from radiation, the

quantity of heat in the steam will be exactly the same after passing the orifice as before passing or the valve-inlet heat quantity.

Consider the following parameters for a sample steam quality determination for the system shown in Figure 10:

- Inlet to pressure reducing valve: 150 psig
- Total energy at 150 psig: 1,196 Btu/lb
- Outlet of pressure-reducing valve: 15 psig
- Outlet temperature (saturated conditions) 15 psig: 249.7°F
- Total energy at 15 psig: 1,164 Btu/lb
- Difference in Btu/lb from high to low pressure: 32 Btu/lb

There is a difference of 32 Btu/lb existing after the pressure-reducing station at the lower steam pressure (15 psig) due to the fact that no external work was accomplished.

The 32 Btu/lb specific energy will create the effect of superheat. Assuming the specific heat of superheated steam to be 0.52, each pound passing through the station will be superheated to 61.5°F (32/0.52). Therefore, the downstream temperature, if 100% steam quality exists, would be 311.2°F.

For the example, if the steam had contained 1% moisture, it would have contained less heat units per pound than if it were dry steam. Since the latent heat of steam at 150 psig is 857.4 Btu/lb, it follows that the 1% of moisture would have required 8.5 Btu/lb to evaporate it, leaving only 23.5 Btu/lb (32 – 8.5) available for superheating. Hence, the superheat would be 45.1°F (23.5/0.52), as against 61.5°F for dry steam.

The degree of superheat for other percentages of moisture may be determined. The action of the throttling calorimeter is based upon several parameters, as follows:

- H = total heat of one lb of steam (inlet steam pressure) to the valve station
- L = latent heat of steam at the inlet to the valve station
- h = total heat of steam at the reduced steam pressure or outlet of the valve station
- t_1 = temperature of saturated steam at the outlet of the pressure reducing station or the reduced steam pressure
- t_2 = temperature of saturated steam pressure at the inlet to the pressure reducing valve station
- 0.52 = specific heat of saturated steam at the outlet steam pressure at the outlet of the valve station
- x = proportion by weight of moisture in steam

The difference in Btu/lb of steam at the inlet valve station pressure and after passing the orifice (valve internals) is the heat available for evaporating the moisture content and superheating the steam. Therefore, the following expressions are given:

$$H - h = xL + 0.52\,(t_2 - t_1)$$

or

$$x = [H - h - 0.52\,(t_2 - t_1)]/L$$

Almost invariably, the lower pressure is taken as that of the atmosphere. Under such conditions, h = 1,163.9 and t_1 = 249.5°F.

A slight error may arise from the value used as the specific heat of superheated steam at the example lower steam pressure of 15 psig: 0.52. However, any error resulting from its use will be negligible. ■

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Economic Indicators

2019 — 2020 — 2021

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CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957–59 = 100)	Oct. '21 Prelim.	Sept. '21 Final	Oct. '20 Final
CE Index	761.5	754.0	595.9
Equipment	956.8	946.5	720.7
Heat exchangers & tanks	819.2	810.6	607.7
Process machinery	962.5	958.5	720.9
Pipe, valves & fittings	1359.9	1330.9	965.1
Process instruments	558.3	551.3	421.0
Pumps & compressors	1177.4	1180.5	1084.0
Electrical equipment	644.6	639.3	568.9
Structural supports & misc.	1043.5	1038.9	755.1
Construction labor	350.0	348.4	337.7
Buildings	780.8	771.9	616.7
Engineering & supervision	310.8	311.1	310.9

Annual Index:

2013 = 567.3

2014 = 576.1

2015 = 556.8

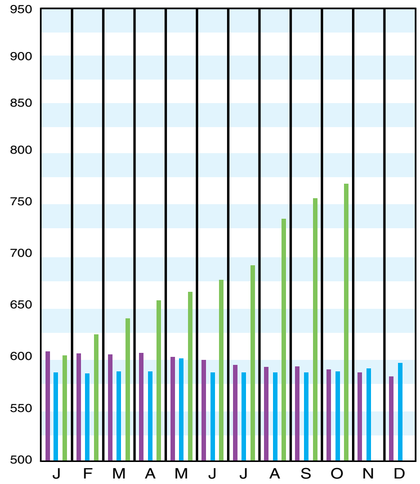
2016 = 541.7

2017 = 567.5

2018 = 603.1

2019 = 607.5

2020 = 596.2

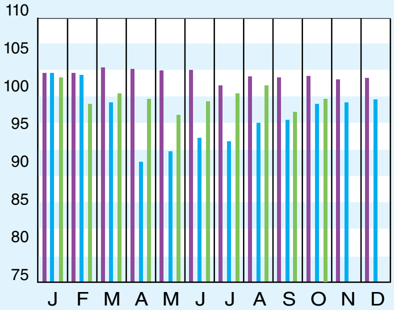


Starting in April 2007, several data series for labor and compressors were converted to accommodate series IDs discontinued by the U.S. Bureau of Labor Statistics (BLS). Starting in March 2018, the data series for chemical industry special machinery was replaced because the series was discontinued by BLS (see *Chem. Eng.*, April 2018, p. 76–77.)

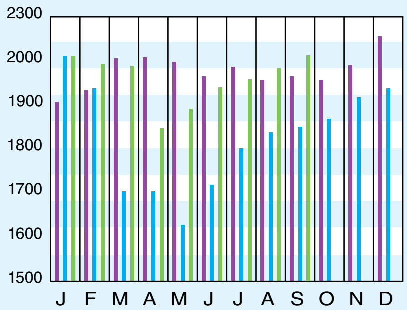
CURRENT BUSINESS INDICATORS

	LATEST		PREVIOUS				YEAR AGO	
CPI output index (2017 = 100)	Oct. '21	= 98.5	Sept. '21	= 97.3	Aug. '21	= 98.3	Oct. '20	= 93.9
CPI value of output, $ billions	Sept. '21	= 2,005.4	Aug. '21	= 1,984.9	Jul. '21	= 1,966.0	Sept. '20	= 1,672.2
CPI operating rate, %	Oct. '21	= 78.5	Sept. '21	= 77.6	Aug. '21	= 78.4	Oct. '20	= 74.6
Producer prices, industrial chemicals (1982 = 100)	Oct. '21	= 335.4	Sept. '21	= 345.2	Aug. '21	= 331.0	Oct. '20	= 227.7
Industrial Production in Manufacturing (2017 =100)*	Oct. '21	= 99.8	Sept. '21	= 98.6	Aug. '21	= 99.3	Oct. '20	= 95.6
Hourly earnings index, chemical & allied products (1992 = 100)	Oct. '21	= 195.9	Sept. '21	= 198.3	Aug. '21	= 193.6	Oct. '20	= 188.6
Productivity index, chemicals & allied products (1992 = 100)	Oct. '21	= 95.4	Sept. '21	= 94.4	Aug. '21	= 356.0	Oct. '20	= 90.4

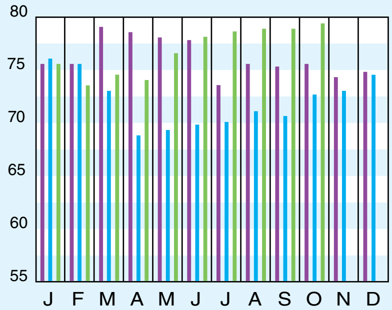
CPI OUTPUT INDEX (2017 = 100)†



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.
†For the current month's CPI output index values, the base year was changed from 2012 to 2017
Current business indicators provided by Global Insight, Inc., Lexington, Mass.

CURRENT TRENDS

The preliminary value for the *CE* Plant Cost Index (CEPCI; top) for October 2021 (the most recent available) is once again higher than the previous month, continuing the upward trajectory of the index that has been observed for the past year. In October, three of the four major subindices that make up the CEPCI saw upticks (Equipment, Building and Construction Labor). The Engineering & Supervision subindex saw a small decline. The current CEPCI value now sits at 21.7% higher than the corresponding value from October 2020. The Current Business Indicators (middle) shown here are the same as those shown in the previous issue because updated data were not available at presstime.